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4.[1] Large-scale Industrial Experiment of the Soviet Union for Selection of the Most Economic Types of Atomic Power Stations, by O.D. Kazachkovskiy.

5. Radioactive Fallouts and Their Consequences for Humanity, by Professor A.V. Lebedinskiy.

6. Radioactive Isotopes in Biology and Medicine, by Professor V. Modestov.

7. Employment of Isotopes and Nuclear Radiation in Research and Industry, by Professor P.L. Gruzin.

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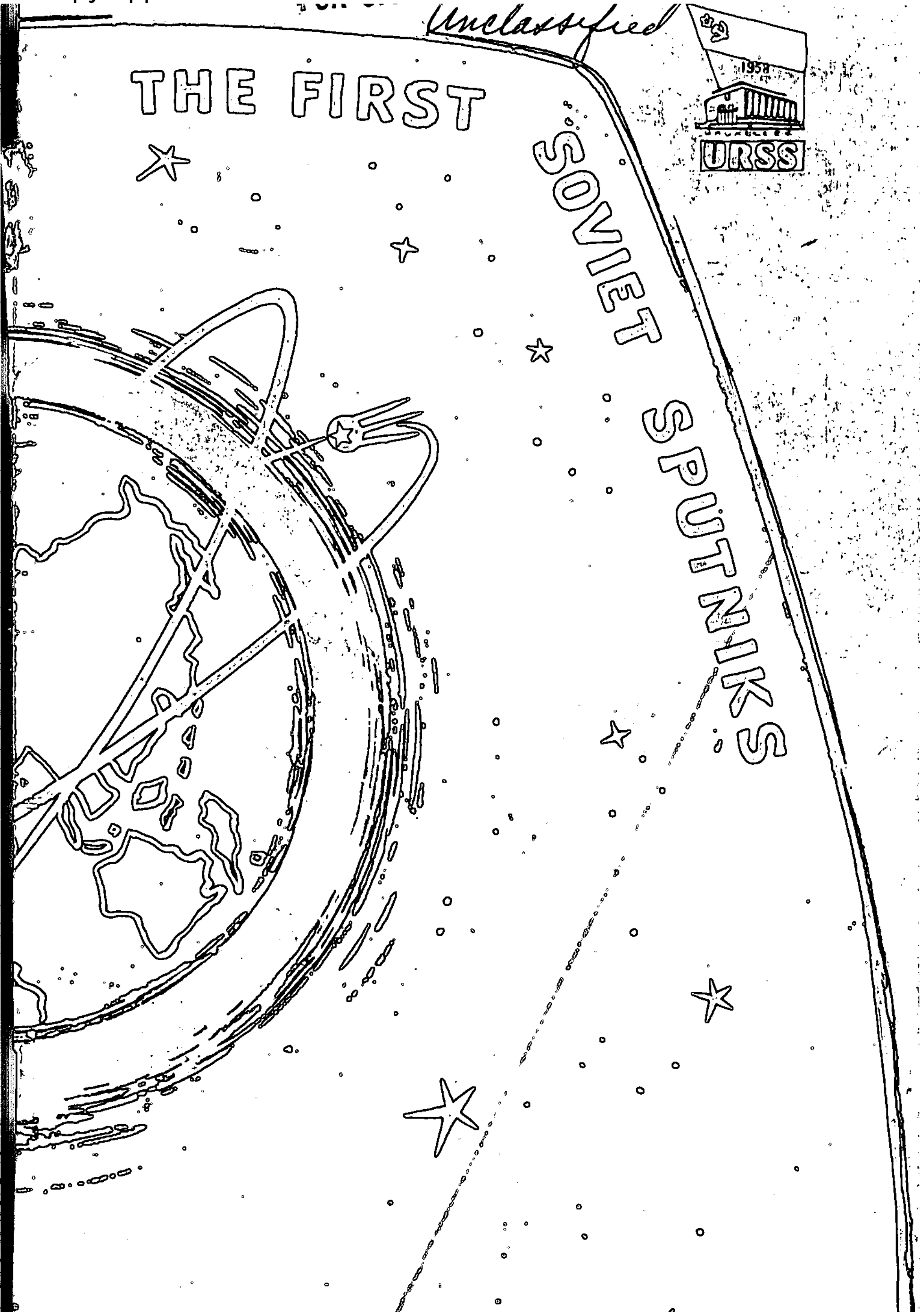

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ACADEMY OF SCIENCES OF THE USSR

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THE FIRST SOVIET SPUTNIKS

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Moscow 1958

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On October 4, 1957 the whole world witnessed an outstanding event: the first artificial Earth satellite was successfully launched in the Soviet Union. The news of this scientific achievement rapidly spread all over the globe, and the Sputnik's movement was recorded by many observers on every continent. A month later, on November 3, another Soviet Sputnik was launched.

The possibility of launching a cosmic ship beyond the Earth's atmosphere with the help of a rocket was theoretically proved early in this century by the eminent Russian scientist K. E. Tsiolkovsky. In his works Tsiolkovsky elaborated a number of cardinal problems pertaining to interplanetary flights and pointed out that the creation of an artificial Earth's satellite would represent the first important stage in man's conquest of interplanetary space.

The creation of the first Sputnik required the solution of many extremely complex and entirely new scientific and technical problems. The greatest difficulties were encountered in developing a carrier rocket to bring the Sputnik into the orbit. A high-precision and effective system of automatic control was elaborated for the rocket to ensure the necessary speed and direction to bring the Sputnik into the orbit.

The solution of these and many other intricate problems was attained only as a result of using the latest achievements of science and engineering in most diverse fields and, above all, due to the high technical level of rocket-engineering in the USSR.

The launching of the Sputnik was preceded by extensive experimental work connected with the development and perfection of separate units and the system as a whole. The successful launching of the Sputnik has fully confirmed the correctness of the calculations and the principal technical solutions accepted in the development of the carrier rocket and the Sputnik.

The launching of the first Sputnik ushered in an extensive program of scientific research which will continue throughout the International Geophysical Year on a number of successive artificial satellites. The creation of the Sputniks is the first step in mastering interplanetary space and carrying out cosmic flights.

The Sputniks' Orbits

The orbit of any satellite resembles an ellipse with one of the foci in the centre of the Earth. The first Soviet Sputniks likewise travelled along elliptical orbits.

For any satellite, orientation of the plane of the orbit in relation to stationary stars remains practically constant. As the Earth rotates around its axis, the satellite should appear over a different area with each successive revolution, shifting by approximately 24° in longitude per revolution. The actual shifting in longitude is somewhat greater, since owing to a deviation of the gravitation field from the central one, the plane of the orbit turns slowly round the Earth's axis in a direction opposite to its rotation. Such a movement of the orbit plane is insignificant and amounts to about a quarter of a degree in longitude per revolution. As a result of the relative movement of the Earth and the plane of the orbit, each successive turn passes more to the west than the preceding one. In equatorial regions the shifting amount to over 2,500 kilometres.

The planes of the Soviet Sputniks' orbits intersect the equator at an angle of 65 degrees, owing to which the Sputniks' course takes them over all the areas of the globe roughly between the Arctic and Antarctic circles. Due to the rotation of the Earth around its axis, the angle of inclination of the path towards the equator differs from the angle of inclination of the orbit plane. When in the Northern Hemisphere, the path crosses the equator at an angle of 69° in the north-east direction. Then the path gradually passes on eastward and, on touching the parallel corresponding to 65° of northern latitude, deviates to the south and crosses the equator in the south-east direction at an angle of 69°. In the Southern Hemisphere the path touches the parallel corresponding to 65° of southern latitude, following which it deviates to the north and again passes on to the Northern Hemisphere.

In the course of time, owing to retardation of the Sputnik in the upper strata of the Earsh's atmosphere, the shape and dimensions of the Sputnik's orbit undergo a gradual change. As the density of the atmosphere is extremely slight at the great altitudes where the Sputnik travels, the evolution of the orbit in the initial period proceeds very slowly. The height of the apogee diminishes faster than that of the perigee, and the orbit approximates more and more a circular one. As the Sputnik enters the dense layer of the atmosphere, its retardation becomes very pronounced. The Sputnik becomes overheated and burns out like meteors coming from interplanetary space and burning out in the Earth's atmosphere.

As the orbit descends, this period diminishes. The speed of change on the period serves as an indication of the speed at which the shape of the orbit changes.

The parameters of the orbits of the Soviet Sputniks make it possible to observe them on every continents in a wide range of latitudes. To launch satellites into such orbits is much more difficult than to launch them into orbits close to the equatorial plane. When a satellite is launched in this way (as for example, in the case of the American satellites), it is possible to make greater use of the speed of rotation of the Earth around its axis to accelerate the rocket.

Observations of the Sputniks' Movement

Observations of the Sputniks have been conducted with the help of radio-engineering devices, as well as at astronomical observatories with the aid of optical

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instruments. Along with experts, radio amateurs have been actively participating, as well as groups of astronomers who have carried on observations from astronomical grounds with the aid of simple optical instruments. In USSR Observations of the Sputniks have been systematically conducted by 70 optical observation stations and various voluntary society clubs supplied with adequate radio-observation equipment.

Research stations conducted observations with the aid of radar and radio bearing. Many photographs recorded the movement of the Sputniks. Amateur astronomers were supplied with a great number of astronomical eyepieces specially manufactured for the occasion and possessing strong lenses with a wide angle of vision. The observation centres have been provided with sets of equipment enabling to determine the position of the Sputnik in the celestial sphere at a specified moment.

The equipment by means of which the optical station records the position of the Sputnik in the celestial sphere permits to make measurements with a precision up to one degree, and the time when the position is noted, with an error not exceeding a second. The optical station observes the Sputnik in the morning or in the evening when the surface of the Earth is submerged in darkness, while the Sputnik itself, being at a great altitude, is lit up by the Sun.

To ensure reliable observations, each optical station arranges one or two «optical barriers» of tubes placed in the meridian and along a vertical circle perpendicular to the visible orbit of the Sputnik.

The radioequipment with the help of which radio amateurs conduct their observations is extremely simple. The news of the Sputnik's movement supplied by the radio amateurs may be used not only in studying the laws of radio wave passage through the atmosphere, but also for roughly determining the elements of the Sputnik's orbit.

All the data of the research stations as well as of the radio and optical observations made by amateurs have been collected and analyzed. This scientific examination has made it possible to determine the elements of the orbit and their secular deviations. Electronic computers have been employed to analyze the observation results. The data supplied by observation stations have been used for a number of geophysical investigations conducted with the help of the Sputnik, such as determining the density of the atmosphere by the evolution of the Sputnik's orbit parameters. The preliminary data have shown that the density of the atmosphere has proved to be substantially greater (7—10 times) than in all the models of the upper atmosphere elaborated so far.

The Sputnik I

The first Sputnik was placed in the nose part of the carrier rocket and covered with a protective cone. The rocket with the Sputnik started up vertically. Shortly afterwards, the axis of the rocket began to deviate gradually from the vertical line with the help of a program device. At the end part of the trajectory where the rocket was brought into the orbit, it moved parallel to the Earth's surface at a speed of 8 kilometres per second. After the jet was expended and the rocket engine stopped, the protective conical nose-cap was dropped, the Sputnik separated from the rocket and began to travel independently.

The first Sputnik had the shape of a sphere. It was 58 centimetres in diameter and weighed 83.6 kilograms. Its hollow hermetically-sealed shell was made of aluminium alloys and its specially treated surface was highly polished. All the apparatus and its power batteries were installed inside the shell of the Sputnik. Before launching the sphere was filled with gaseous nitrogen.

Four rod-like antennas 2.4 to 2.9 metres in length were attached to the outer shell of the sphere. When the Sputnik was being placed in its orbit, the antenna rods were pressed to the shell of the rocket.

During the first days after launching, the Sputnik circled the Earth every 96 minutes and the maximum distance separating it from the Earth amounted to 947 kilometres.

While moving along the orbit, the Sputnik was periodically subjected to sharply fluctuating heat effects, beeing heated by the rays of the Sun when above the lit up side of the Earth, cooled on entering the shadow of the Earth, and being subjected to the thermal effect of the atmosphere. In addition, a certain amount of heat is produced inside the Sputnik during the operation of its equipment. As far as heat is concerned, the Sputnik is an independent celestial body which exchanges radiant heat with the surrounding space. To maintain normal temperature conditions in the Sputnik, required for the operation of its equipment, was therefore a new and complex problem. This was effected in the first Sputnik by providing its surface with proper values of radiation and solar radiation absorption factors as well as by using forced circulation of nitrogen inside the Sputnik.

Two radio transmitters were installed on the Sputnik, which uninterruptedly emitted signals with frequencies of 20.005 and 40.002 megacycles (the wave lengths 15 and 7.5 metres respectively). It should be noted that due to the relatively great weight of the Soviet Sputniks, it was possible to install there highpowered radio transmitters. This permitted to receive signals from the Sputniks at very great distances and enabled vast numbers of radio amateurs throughout the world to take part in observations of the movement of both Sputniks.

The signals emitted by the radio transmitters on each frequency resembled telegraph clicks. A signal of one frequency was sent during the interval between the signals of another frequency. On the average the signals on each of the frequencies lasted for about 0.3 sec. The signals were used for observing the orbit of the Sputnik as well as for solving a number of scientific problems. To record the processes occurring on the Sputnik, the latter was provided with sensitive cells which changed the frequency of the telegraph signals and the relationships between the duration of these signals and the intervals with a change in some parameters in the Sputnik (for instance, temperature).

The results obtained by measuring the intensivity of the radio signal field permit to appraise the absorption of radio waves in the ionosphere, including the regions

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lying above the maximum of the basic layer ionization. The measurements provide material on the possible ways of radio wave propagation in the ionosphere.

The results of receiving the Sputnik's radio signals and the measurements of their levels have shown that on the 15-metre wave the signals were received at very great distances, far exceeding direct visibility distances. Such distances were as great as 10,000, 12,000 and even 15,000 kilometres, and even greater in some cases.

Of particular interest is the fact that moving along an elliptical orbit, the Sputnik occupies varying positions in relation to the basic maximum of electronic concentration in the Earth's atmosphere. Whereas in the Southern Hemisphere the Sputnik travels above the ionosphere layer, in the Northern Hemisphere it may pass both above and below the maximum ionization of the layer, and sometimes near that maximum. Such conditions create a variety of ways in which short radio waves propagate at great distances. One of the ways consists in that the radio waves which have passed from above through the entire thickness of the ionosphere are reflected from the Earth's surface. This is followed by a single reflection from the ionosphere in its regions where the critical frequencies are sufficiently great. In other cases the radio waves descending from above on the ionosphere at certain angles are considerably refracted in the ionosphere and, as a result, penetrate into a region which lies beyond direct visibility.

The position of the satellite near the region of maximum ionization of the atmosphere creates particularly favourable conditions for the radio wave propagation by ionosphere radio wave guides. As shown by observations, in some cases the radio waves arrived at the point of reception not by the shortest route, but by passing around the globe along a longer arc of the large circle. The phenomenon of a round-the-world echo of radio signals was recorded in some cases. Sometimes the measured values of field intensity have proved to be greater than calculated values, which likewise testifies to the presence of wave guide channels in the ionosphere.

Interesting results have been obtained in observing the Doppler effect by recording on a magnetic tape changes in the current of the beats between the frequency of the radio waves emitted by the Sputnik and that of the oscillation of a local heterodyne.

The Sputnik II

The second Soviet Sputnik represents the last stage of the rocket containing all the scientific and metering apparatus. Such a disposition of the apparatus simplified the problem of determining the Sputnik's coordinates by means of optical observation devices, since the observation of the carrier rocket proved to be considerably simpler than of the Sputnik itself. The brightness of the carrier rocket is superior to that of the first Sputnik by several star values. The total weight of the new Sputnik's scientific and radio equipment, batteries and a container with the dog Laika is 508.3 kilograms.

When being placed in its orbit, the rocket rose to a height of several hundred kilometres above the surface of the Earth, and at the end of the section, where it was brought into the orbit, its last stage travelled parallel to the surface of the Earth at a speed of over 8 kilometres per second and became a satellite of the Earth.

The second Sputnik's greatest distance from the Earth amounted to some 1,700 kilometres, which is almost double the maximum height attained during the launching of the first Sputnik. Since the dimensions of the large half-axis of the second Sputnik's orbit are greater than those of the first Sputnik, the time of its rotation round the Earth likewise proved to be longer and amounted to 103.7 minutes at the beginning of its movement.

The second artificial Earth satellite can well be called a cosmic laboratory. It contains various types of registering, analyzing and transmitting equipment — for studying solar radiation in the ultra-violet and X-ray regions of the spectrum, a spherical container with radio transmitters and other equipment, and a hermetically-sealed container with the experimental animal. The equipment for studying cosmic rays was installed on the shell of the rocket. The devices and containers mounted on the frame are protected against aerodynamic and heat effects occurring during the flight of the rocket in the dense layers of the atmosphere by a special conical nose-cap. The latter was dropped after the last stage of the rocket had been placed in the orbit.

The radio transmitters placed in the spherical container operated on frequencies of 40.002 and 20.005 megacycles. The container also houses the power supply sources, the system of thermal control and the sensitive cells which record changes in the temperature and other parameters.

The signals of the radio transmitter which operated on a frequency of 20.005 megacycles (wave length: 15 metres) resembled telegraph outputs. The duration of the signals and the intervals between them averaged about 0.3 sec. When some parameters inside the spherical container (temperature, pressure) changed, the duration of the signals and the intervals between them likewise changed within certain limits.

The radio transmitter operating on a frequency of 40.002 megacycles (wave length: 7.5 metres) emitted continuous signals. The installation of two radio transmitters on the above frequencies provided data on the propagation of radio waves emitted from the satellite and on the measurement of the parameters of its orbit. At the same time this ensured reception of signals from the satellite at any state of the ionosphere.

The hermetically-sealed container with the experimental animal (the dog) is of a cylindrical shape. To create conditions necessary for the normal existence of the animal, the container was provided with a supply of food and an air-conditioning system, consisting of a regeneration chamber and a heat-control system. Apart from this, the container included apparatus for recording the dog's pulse, breathing and blood pressure, equipment for making electrocardiograms, as well as sensitive cells for measuring a number of parameters defining the conditions inside the container (temperature, pressure).

The animal's container, like the spherical one, was

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made of alluminium alloys. Their surface was polished and specially treated so as to provide it with the required values of emission and solar radiation absorption factors. The heat-control systems installed in the spherical and the animal's containers maintained the required temperature, removing the heat towards the shell by means of forced circulation of gas.

In addition to the above-mentioned apparatus, the last stage of the rocket contained the following: radiotelemetric measuring equipment, probes for taking the temperature, and power supply sources. The temperature of the outer surface and inside the animal's container, as well as that of individual devices and parts of the unit was determined by means of temperature probes installed on them. The radiotelemetric equipment was helpful in transmitting scientific data to the Earth. It was switched on periodically, according to a predetermined program to transmit the results of soundings and measurements taken in flight.

Scientific Measurements in the Second Sputnik

The artificial Earth satellite has enabled scientists to carry out for the first time a number of experiments in the upper layers of the atmosphere, which hitherto could not have been conducted.

Short-Wave Radiation of the Sun

Investigations of recent years have shown that in addition to the visible light, the Sun emits radiation extending to a wide range of wave lengths, beginning with X-rays with a wave length of approximately several one-hundred-millionths fractions of a centimetre, and ending with a radio wave length of a few metres.

The emanation of the Sun's short-wave radiation (ultra-violet and X-ray radiation) as well as radio emission is related to physical processes occurring in the outer layers of the Sun's atmosphere (the chromosphere and the corona), which have been inadequately studied, and has a great effect on the Earth's atmosphere. The chief radiation of the Sun's chromosphere is concentrated in the spectral line of hydrogen with a wave length of 1,215 angstrom (1 angstrom is equivalent to a hundred-millionth part of a centimetre), situated in the remote ultra-violet region of the spectrum, and the radiation of the corona in the region of soft X-rays (3—100 angstroms). The corona, which consists of highly rarefied matter, has a temperature close to a million degrees centigrade and the corona appears to have regions with a still higher temperature. So far the nature of the corona has remained a mystery to be unveiled.

The total energy of the Sun's short wave radiation is comparatively small — tens of thousands of times less than that radiated by the Sun in visible light, but it is precisely this radiation that exerts an extremely great influence on the Earth's atmosphere. This can be explained by the fact that short-wave radiation possesses a very high activity and is capable of ionizing the molecules of the air, causing the formation of ionosphere, i. e., greatly ionized upper layers of the atmosphere. According to prevailing conceptions, the lower layer of the ionosphere, situated at an altitude of 70—90 kilometres, was formed through ionization of the air molecules by radiation of the spectral line of hydrogen emitted by the chromosphere, and the next layer, situated at an altitude of 90—100 kilometres, by X-ray radiation of the corona.

The state of the upper layers of the Sun and the ionosphere does not remain constant: it changes continuously.

The Earth's atmosphere completely absorbs the ultra-violet radiation of the Sun, letting through only the region of the near-by ultra-violet radiation adjacent to the violet end of the visible part of the spectrum.

Three special photoelectronic multipliers placed at an angle of 120 degrees to one another were used as radiation receiving sets. Each photomultiplier was successively covered up with several filters made of thin metal and organic films as well as of special optical materials, which permitted to isolate various ranges in the X-ray region of the Sun's spectrum and the hydrogen line in the remote ultra-violet region. The electric signals produced by the photomultiplier, which was directed towards the Sun, were amplified by radio appliances and transmitted to the Earth by means of a telemetric system.

As the satellite continuously changed its orientation in relation to the Sun and travelled part of the time on the section of its orbit that was not lit up by the Sun, the equipment power supply sources were switched on only when the Sun got into the field of vision of one of the three receiving sets of light. The sources were switched on by means of photoresistances

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lit up by the Sun simultaneously with the photomultipliers.

Simultaneously with observations of the Sun's radiation from the satellite, the Sun was observed by the entire network of the «Sun Service» ground stations, which conduct their work in accordance with the program of the International Geophysical Year. The observations were made by astrophysical observatories and special stations set up to study the ionosphere and to receive the Sun's radio emission.

Study of Cosmic Rays

In the depth of cosmic space the atomic nuclei of various elements are accelerated and acquire exceedingly high energies. On the way from the point of their origin to the Earth cosmic rays are subjected to the effect of the environment through which they pass. As a result of a number of atmospheric processes, the composition of cosmic rays and the intensity of this radiation undergo definite changes. The number of particles of cosmic rays changes if intensive explosion processes take place on the Sun and conditions are created to accelerate the particles to high energies.

The Sun is also a source of corpuscular radiation. In the streams of corpuscular radiation there are intensive magnetic and electric fields which affect cosmic rays. These streams may be studied at great distances from the Earth with the help of cosmic rays.

While passing through the magnetic field of the Earth, the particles of cosmic rays greatly deviate in that field. Only particles possessing exceedingly high energies are capable of reaching freely any region of our planet. The smaller the energy of the particles, the smaller the area of the regions on the Earth which prove to be accessible to these particles. Small-energy particles can only reach the areas of the Arctic and Antarctic zones. Hence, the Earth is surrounded, as it were, by an energy barrier. Reaching its climax on the equator, the height of that barrier diminishes with an increase in the geomagnetic latitude. Equatorial areas can be reached only by cosmic protons possessing an energy of over 14,000 million electron-volts. The southern areas of the Soviet Union are accessible to particles with an energy exceeding 7,000 million electron-volts. By measuring cosmic rays at various latitudes, it is possible to determine how many particles of specified energies are present in the composition of cosmic rays. The dependence of the number of particles of cosmic radiation on latitude (the so-called latitude effect) determines the distribution of particles by the energies, i. e., the energy spectrum of cosmic rays.

As a result of a number of processes to which cosmic rays are subjected in the outer space, their number and composition undergo changes.

In order to disclose the nature of the changes occuring in cosmic rays, it is necessary not only to establish the fact of an increase or decrease in the intensity of cosmic rays, but also to determine the change in the number of particles of various energies. While moving at a speed of 8 kilometres per second, the satellite passes from one latitude to another in a very brief space of time. Hence, by measuring cosmic rays

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on the satellite, it is possible to define the latitude effect of this radiation and, consequently, the distribution of the particles of the radiation by energies. Of particular importance is the fact that such measurements are conducted many times. Hence, with the help of the Sputnik it is possible to follow not only the changes in the intensity of cosmic radiation, but also the changes in its composition.

The particles forming part of the composition of cosmic radiation were recorded on the satellite by means of charged-particle counters. When an electrically charged particle passes through the counter, there arises an impulse which is transmitted to a radio engineering device assembled on semiconductor triodes and intended to count the number of cosmic-ray particles and emit a signal when a certain number of particles has been counted up. After a signal is transmitted over the radio to the effect that a certain number of particles have been counted up, the particles of cosmic radiation are recorded again, and a new signal is given as soon as the same number of particles has been counted up. By dividing the number of recorded particles by the time during which they have been counted, it is possible to obtain the number of particles which pass through the counter per second, i. e., the intensity of cosmic rays.

Two identical devices were installed in the satellite to record charged particles. The axes of the counters of both devices were placed in reciprocally perpendicular directions.

The measurements helped to establish for the first time the dependence of the full intensity of cosmic radiation on the altitude (up to 700 kilometres). It has been observed that the full intensity increased at great altitudes by approximately 40 per cent as compared with the height of 200 km. The latitude effect of cosmic radiation has been observed and variations of cosmic rays have been registered. A further study of cosmic rays with the aid of the satellite will make it possible to solve a number of interesting problems pertaining to cosmic radiation.

Study of Biological Phenomena during Cosmic Flight

To study a number of medical and biological problems, the satellite was supplied with a special hermetically-sealed container with the dog Laika, metering apparatus to examine the physiological functions of the animal, as well as equipment for air conditioning, feeding the animal and removing the products of its vital activity.

Operating for a long period of time, the apparatus helped to record, by means of a radiotelemetric system, the animal's pulse and respiration rates, its arterial blood pressure and biopotentials of the heart, as well as the temperature and air pressure inside the container.

In view of the absence of air convection in conditions of loss of weight, a system of forced ventilation was devised in the animal's container. The temperature of the air in the container was maintained within certain limits by a heat-control system.

A special system of feeding Laika was devised in preparation for her flight. Besides, the first space traveller went through a thorough course of training. Gradually it got accustomed to special clothing and the instruments attached to it. It learned to live in a tiny compartment and in conditions similar to those in which it was to fly in space. The dog was also trained to bear the effect of overloading. The animal's resistance to the effect of vibration and to some other factors was determined on laboratory stands. Due to its long training, the animal was able to endure the stay in the hermetically-sealed container for several weeks, which provided the possibility of carrying out the necessary scientific investigations.

A study of the biological phenomena during the flight of a living organism in cosmic space has become possible only as a result of preliminary experiments on animals during brief rocket flights to a height of 100—200 kilometres, which were practised in the USSR for a number of years.

Unlike previous experiments, the flight of the animal in the satellite has permitted to study the protracted effect of «weightlessness». Up till now the effect of loss of weight could be investigated only for a few seconds in airplanes and for a few minutes during rocket flights. The flight in the satellite has permitted to examine the state of the animal's organism in conditions of weightlessness.

A profound study of the observations has proved that cosmic flights of living beings are quite possible.

The program of scientific measurements in artificial Earth satellites is very extensive, embracing many branches of physics pertaining to the upper layers of the atmosphere and the study of cosmic space near the Earth.

These problems include a study of the state of the ionosphere and its chemical structure, measurements of pressure and density, magnetic measurements, research into the nature of the Sun's corpuscular radiation, the primary composition and variations of cosmic rays, the ultra-violet and X-ray sections of the Sun's spectrum, electrostatic fields of the upper layers of the atmosphere and microparticles, etc. The first satellite has provided valuable information on some of these problems.

In the field of studying cosmic rays, the program envisages to obtain data on the relative amount of various nuclei in the composition of primary cosmic radiation. Among other things, the relative amount of the lithium, beryllium and boron nuclei, as well as of nuclei with very great charges will be defined.

Along with the Sun's short wave radiation, the Sun's corpuscular radiation plays a major role in the processes occurring in the upper layers of the atmosphere. For this purpose it is important to solve the problem of the nature of corpuscular radiation, of its intensity and of the energy spectrum of the particles ejected by the Sun, and to study the role of the Sun's corpuscular radiation in the formation of Aurora borealis. It will likewise be possible to solve these problems with the aid of the equipment installed in the artificial Earth satellites.

The flight of the satellite over ionized layers of the atmosphere will permit to verify a number of conlusions drawn from various hypotheses regarding the circular currents existing in the upper layers of the atmosphere. The artificial satellites also make it possible to study the rapid variations of the Earth's magnetic field.

Of considerable interest is the study of electrostatic fields at great altitudes (up to 1,000 kilometres). Another interesting problem awaiting solution is to find out whether the Earth together with its atmosphere is a charged or a neutral system. Along with studying the ionosphere through indirect methods by observing the passing of radio waves, the outlined program of investigations provides for direct measurements of ionic concentration at various altitudes to be followed by a study of the chemical composition of the ionosphere. Many contemporary scientists believe that negative ions are not to be found at great altitudes. The answer to that problem is to be furnished by the experiments which will provide full information on the composition of the ionosphere.

The launching of the first two Sputniks in the Soviet Union is an important contribution to the study of the upper layers of the atmosphere, which will greatly enhance man's knowledge of the Universe.

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EMPLOYMENT OF ISOTOPES AND NUCLEAR RADIATION IN RESEARCH AND INDUSTRY

by

Professor P.L. Gruzin
Doctor of Physics and Mathematics

Our age is quite correctly called the age of atomic power. The discovery and the employment of atomic energy is the greatest achievement of modern science and engineering. Science has given man an inexhaustible source of power, a mighty means for technical progress and swift growth of the productive forces.

The search for rational methods of obtaining atomic energy ranks prominent in the problem of utilisation of nuclear physics achievements. One can easily appreciate the importance of this aspect of the problem.

The other aspects of the discussed problem are of great importance too. In particular, the employment of radioactive isotopes and nuclear radiation may be most efficient in various fields of science and engineering. The research into these problems holds one of the major places in the Soviet Union in the problem of atomic energy employment for peaceful purposes. This report will discuss only the most indicative results of the research carried out in the Soviet Union mainly in the sphere of physics and engineering with the employment of isotopes and nuclear radiation.

It is of interest to note that the employment of radioactive isotopes and nuclear radiation for purposes of scientific research commenced long before the discovery of the artificial radioactivity. One of the first works in this sphere was the research made by Kheveshi and Obrucheva into self-diffusion in lead (1920-1921). Of great importance for the development of the radioactive indicator method was the research made by Khlopin, Pisarzhevsky and other Russian scientists who studied the methods of obtaining isotope indicators and who studied certain physico-chemical processes.

1. Research into solid state physics

Large scale employment of isotopes and nuclear radiation in solid state physics began in 1949-1950. The majority of the papers published on this problem were devoted to the migration of atoms, the inter-atomic reciprocity and the microdistribution of elements in metals and in ionic crystals. A prominent place is occupied by the papers devoted to the influence of nuclear radiation upon the properties and the kinetics of phase transformation in solids, and also to the research into metal structure by neutronography. Stable isotopes in combination with the method of mass-spectrometry find application in the study of metal behaviour under different conditions.

The development of technique requires the creation of heat-resistant steels, alloys and other metallic materials with diverse physical and mechanical properties. Such tasks can be successfully settled only if there is a profound knowledge of smelting and the behaviour of metals under various conditions, a thorough and comprehensive control of quality of important metal parts. The knowledge of regularities governing the phenomena of diffusion (directed movement of atoms), interatomic reciprocity and the distribution of elements in solids gives the key for the solution of many practical tasks associated with the search for and employment of various steels, alloys, ceramic and organic materials. These factors, for instance, predetermine the durability of materials, the length of service and the temperature ceiling of heat-resistant alloys which is determined in a certain degree by the peculiarities of the influence of metal structure upon their properties. It is known, for instance, that only by obtaining heat-resistant alloys in a strengthened state the latter can meet the necessary requirements. This state, however, changes when the alloys operate in the region of high temperatures due to a re-grouping of atoms in certain elements of the alloy; these changes are basically of a diffusion nature. The employment of radioactive isotopes and of other achievements of nuclear physics has helped us in a great measure during the recent few years to solve these and similar questions.

At present, in order to study the diffusion in solids, that is in order to determine the quantitative characteristic of the process associated with the movement of the atoms radioactive isotopes are used of iron, cobalt, nickel, chrome, tungsten, molybdenium, silver, copper, phosphorus, sulphur, calcium, and of many other elements. The employment of isotopes for these purposes offers tremendous advantages. Firstly, the determination time of the diffusion characteristic is reduced greatly, secondly, we receive a possibility to study the self-diffusion process, i.e. the mixing of uniform atoms of metal influenced by thermal movement. However, the most important in this respect is that the employment of isotopes opens up new ways for a more profound study of atomic migration in liquids and solids. Hence, the study of inter-atomic reciprocity, the nature of atomic movements and the patterns of microdistribution of elements comprise one of the basic problems of solid state physics. Let us now review briefly certain results of metal study obtained mainly in our country from 1949 to 1957. We shall devote particular attention to the mobility of atoms and to the nature of interatomic reciprocity.

The very first experiments on self-diffusion in metals with the employment of artificial radioactive isotopes were made in 1937 at the Institute of Physics of Metals of the Urals Branch of the Academy of Sciences of the USSR. Radioactive isotopes were first used for the determination of diffusion parameters in 1949 at the Institute of Metal Studies and Physics of Metals of the Central Scientific Research Institute of Ferrous Metals. The research made during the past few years has given us extensive data and helped us to discover a number of regularities. This was preceded by the elaboration of certain methods of research.

Reliable results are obtained during the research into volume diffusion in solids by the method of the integral radioactivity of sample residue. A distinctive feature of this method is that the diffusion coefficient is determined by the data of measuring the integral radio-activity of the remaining part of the flat sample during consequent removal of a number of layers from it. This method is performed most simply when the radioactive isotopes of the diffuse substance either has a hard or a very soft radiation ($E_\beta \geqslant 0.5$ and $E_\beta \leqslant 0.2$ mev). If the radioactivity energy is restricted to 0.2 and 0.5 mev. range, it is necessary to consider the radiation absorption in the diffusion layer.

When flat diffusion sources of small thickness and homogeneous distribution of the radioactive atoms are used, the formulas for calculating the diffusion coefficients are obtained from the following expression for the integral radioactivity of sample residue I_n when a layer of X_n is removed from it;

$$I_n = \text{Const} \cdot e^{(\mu^2 Dt + \mu X_n)} \left\{ \text{erf}\left(\frac{X_n + \lambda}{2\sqrt{Dt}} + \mu\sqrt{Dt}\right) - \text{erf}\left(\frac{X_n}{2\sqrt{Dt}} + \mu\sqrt{Dt}\right) \right\} \quad (I)$$

where D - is the diffusion coefficient;
t - is the diffusion annealing time
μ - is the radioactive radiation absorption coefficient in the sample.
λ - is the thickness of the complete radiation absorption layer.

When we analyse the relations (1) it is important to notice the cases when:

a) $\mu \ll 1$; b) $\mu \cong 10^2$; c) $\mu \gg 10^2$, which correspond to the employment of isotopes with hard, medium and soft radiation. The consideration of these conditions gives the following relations:

$$\text{a) } \ln \frac{\partial I_n}{\partial X_n} = -\frac{1}{4Dt} X^2 + \text{Const.}$$

$$\text{b) } \ln \left(\mu I_n + \frac{\partial I_n}{\partial X_n}\right) = -\frac{1}{4Dt} X_n^2 + \text{Const.} \qquad (2)$$

$$\text{c) } \ln I_n = -\frac{1}{4Dt} X_n^2 + \text{Const.}$$

The logarithm in the left part of the equation (2) is the linear function of X_n^2. The tangent of the α angle formed by these lines with the X_n^2 axis, is 1/4 Dt. Thus, we obtain the formula for calculation:

$$D = \frac{1}{4 \, \text{tg}\, \alpha \cdot t} \qquad (3)$$

Table 1.

Parameters of silver selfdiffusion (Do and Q)

Do cm^{2}sec^{-1}	Q, Cal/gr-at	Methods
3.00	45.50	Integral radioactivity measuring
0.895	45.95	Thin layer etching
1.80	47.70	Radiation absorption
0.905	45.00	

This method is both simple and universal. The verification of this method carried out during the study of selfdiffusion in silver, cobalt and nickel gave satisfactory results (table 1, fig.1). In some of the cases this method helps to discover the intracrystallite diffusion. It was instrumental in providing extensive data concerning diffusion in high melting alloys and in ceramic materials.

The methods based on the determination of the sample integral radioactivity without destroying it belong to another group. Two private methods are considered to be promising. The method of integral radioactivity relations and the method of the integral radioactivity of the kinetic curve. The former is founded on the measuring of the intensity of the soft and hard regions of the spectrum of the sample radiation (see diagram fig.2). The conditions of the experiment are such that the diffusion is accompanied by a material decrease in the intensity of the soft region of the radiation spectrum only. The relation of the intensity of the soft region of the spectrum is taken as a standard of the diffusion process in the sample. The method is simple when the isotope has beta and gamma radiation. The gamma radiation (or the hard component of the beta spectrum) in this case serves as a standard for the determination of the change in the intensity of the soft region of the sample radiation spectrum. This method delivers us of the necessity to consider the changes in the sample size and other factors. It might prove to be particularly effective in measuring the kinetic curve of the integral radioactivity relations. The verification of this method during the study of cobalt diffusion in iron alloys and during the self-diffusion in circonium gave good results which are presented in table 2.

Table 2

Coefficients of circonium selfdiffusion

Temperature °C	D, cm^2 sec^{-1}	
	Method of relations	Method of integral radioactivity of sample, residue
721	$5.0 \cdot 10^{-13}$	$5.7 \cdot 10^{-13}$
765	$1.6 \cdot 10^{-12}$	$1.6 \cdot 10^{-12}$
818	$4.4 \cdot 10^{-12}$	$3.2 \cdot 10^{-12}$

Another method of the second group deserves particular attention. The workers of the Central Scientific Research Institute of Ferrous Metals have found an expression for the kinetic curve of the sample integral radioactivity by using definite concepts concerning the nature of the volume and boundary diffusion in a polycrystallic body. This way it is possible to appreciate the parametres of the volume and boundary diffusion. An important peculiarity of this method consists in the standardisation of the sample integral radioactivity by the hard region of the radiation spectrum and the consideration of the radiation reflection influence in the diffusion layer.

Certain other private methods are also employed.

Particularly important is the autoradiographic method of diffusion investigation. A characteristic peculiarity of this method is that it offers an opportunity to observe the topography of diffusion streams (fluxes) in solids and to appreciate the value of boundary diffusion coefficients.

Selfdiffusion in silver, nickel, iron, cobalt, titanium, circonium and also in chrome, tantalum, molybdenium and tungsten has been studied in a big range of temperatures. For these metals the temperature dependence of selfdiffusion coefficients is above the recrystallisation temperature and is expressed exponentially. Qualitatively the selfdiffusion in hard melting metals may be described by the selfdiffusion parametres - the preexponential multiplier and the activation energy. The selfdiffusion parametres under these conditions are physical properties of the metals, which are connected by definite relations with the melting temperature, the sublimation temperature and the linear expansion coefficient, as well as by certain other constants of solids. These relations help to determine the value of metal selfdiffusion parametres and to ascertain our knowledge regarding the mechanism of atomic movement in solids.

Attention is drawn to the fact that the level of diffusion mobility for every chosen temperature changes radically in the transition from one metal to another.

The values of selfdiffusion coefficients for aluminium, iron and tungsten differ in the range from 500 to 1000°, by more than 10 orders. This peculiarity cannot fail influencing the nature of metal behaviour in high temperatures. Apparently, the occurrence of certain similar processes associated with the movement of atoms within the metal is determined by this peculiarity. We may class with these processes recrystallisation, melting, creep and the resoftening of metals at high temperatures. The melting and the recrystallisation of metals is characteristic of definite threshold levels of diffusion atom mobility. These levels correspond to selfdiffusion coefficients of 10^{-22} cm^2. sec.$^{-1}$ during recrystallisation and 10^{-8} cm^2. sec.$^{-1}$ during pure metal melting. Fig.3 presents the temperature dependencies of selfdiffusion coefficients for a number of metals describing their diffusion mobility levels.

It should be also noted that the correspondence between the diffusion mobility levels and the melting temperatures is not observed for all the metals. Titanium and circonium are the exceptions and they are characteristic of very high diffusion mobility levels compared with the metals which have approximately the same melting temperatures. This anomaly seems to be associated to a certain extent with the peculiarities of structural changes which occur in circonium and titanium during phasial transformations.

The determination of causes which entail the circonium anomaly is of great practical importance. The point is that circonium and its alloys are used in atomic power installations.

Circonium satisfies the necessary requirements regarding the cross-section of thermal neutron capture and has high plasticity. However, circonium and its alloys, in the group of hard melting metals have a comparatively low level of heat and corrosion resistance. This peculiar behaviour of circonium is to a certain degree a result of its abnormally high level of diffusion mobility. One of the reasons for this anomaly might be the influence of the substructural factor on the diffusion. The influence can be determined not only by the alteration in the length of intragrain boundaries but also by the nature of distribution of admixtures in microvolumes when there are intragrain boundaries. The elucidation of all these questions is of extreme importance for the successful development of research with a view to finding the necessary circonium alloys.

During the past few years data has been obtained about the alloying influence upon diffusion in iron-carbon, iron-chrome, iron-manganese, iron-nickel, iron-nickel-carbon, iron-nickel-chrome, iron-cobalt, cobalt-chrome, cobalt-chrome-carbon and nickel-chrome alloys. These show that the introduction of carbon into the metals of iron group substantially increases the mobility of metal atoms and weakens the intra-atomic bonds. This carbon influence on metal diffusion apparently has a general nature.

In this connection the question presents itself as to the influence upon diffusion and intra-atomic bonds of metals offered by other elements which form solid solutions of incorporation with the metals of the iron group (particularly gases -- hydrogen, oxygen, nitrogen). It is possible that this influence will be similar to that of carbon. The specific carbon influence on diffusion and intra-atomic bonds is apparently due to the peculiar state of its atoms in the crystal lattice. Chrome, molybdenium, and nickel belong to the elements which under given conditions may retard selfdiffusion in iron. The common feature in the influence of alloying upon metal diffusion in alloys is that during the alteration in the composition of a solid solution of a given metal the diffusion mobility level changes by a value which is much inferior to the change observed in the transition to solid solutions based on a metal with a higher melting point. A similar phenomenon occurs in the absence of phase transitions in the solvent. It is of interest that a corresponding pattern is observed in carbon diffusion in iron and nickel, where a comparatively small shift of the diffusion mobility level takes place during alloying.

The available data indicates that the selfdiffusion and diffusion coefficients for a number of alloys at the rectrystallisation temperature have a value of the order of $10^{-11} - 10^{-13}$ cm^2. $sec.^{-1}$. Hence, the threshold diffusion mobility levels of pure metal and their alloys recrystallisation have different values (fig.3). In the first case it is determined by the selfdiffusion coefficients of such value as 10^{-22} and in the second case - 10^{-13} cm^2. sec^{-1}. Apparently the reason for this is that the alloying of metals entails the change in the value of atomic migration necessary for the alloy recrystallisation process.

The rate of atomic migration is altered as a result of the formation of various dislocations in the structure of the metal. This also determines the influence of length and state of intracrystallite bounderies upon diffusion. It has been determined that under definite conditions the boundary planes which occur within separate metal grains in deformation or phase transitions are quite important. The crystal lattice may have big deformations in the metal layers close to the interfaces. In the alloys, the boundary planes may entail a change in the alloying element concentration in the boundery layers. Therefore, under definite conditions an extention or shortening in the length of interfaces in fact influences the diffusion of elements, the atoms of which are capable of forming solid solutions of substitution. The direct dependencies of the diffusion coefficient logarithm upon the inverse temperature for steel and iron-nickel and iron-manganese alloys where phase transitions take place, the grain structure influence displays itself in the form of a fracture in the area of 1000-1100°. This effect is detected with particular clarity during the diffusion of alloying elements in iron and steel.

During the diffusion of cobalt and tungsten in steel in the region of low temperatures the diffusion coefficients increase by 2-3 orders compared with those which are determined by the exponential dependence, which is valid for high temperatures (fig.4). No acceleration of diffusion is observed in the metals and alloys where transformations do not take place neither at heating nor cooling. It has been shown in one of the works that the above described effect is absent during the diffusion of carbon in the alloys of iron-nickel (25%) - manganese (2%), where the fractioning of grains was accomplished by martensite transformation. It may be assumed that the absence of the grain structure influence upon carbon diffusion is due to the peculiarities of the crystal lattice structure of iron-carbon alloys. The formation of the bounderies within the crystals apparently has a very low influence upon the change in the force field at the points of carbon atoms localisation in the lattice.

The study of the grain structure influence upon diffusion deserves particular attention. The study of the results obtained in this field helps to understand certain peculiarities of steel and alloy behaviour during hardening. For instance, it is known that durable and strong steel may be obtained by hardening. However, Chernov, the father of scientific metalography, had discovered as far back as in the last century that there is a certain region of temperatures where hardening of steel heated to these temperatures does not bring about the desired results. The steel, either does not become hardened (has insufficient strength and durability) or yields unstable results as regards hardness and other properties. The explanation of certain details of this phenomenon has been made possible only thanks to the findings obtained in the study of structural factor influence on the diffusion of alloying elements in steel (see fig.4). The point is, that when steel is brought to a temperature of hardening there takes place an alteration in its grain structure. In this case, as a result of a phase transition separate grains of the high temperature γ-phase (austenite) are divided into smaller blocks. Hence, there appear new bounderies within the metal grains which entail a substantial acceleration of the diffusion. As a result the diffusion processes are not retarded during the hardening, i.e. steel in fact does not become hardened, or, as has been already noted, its properties do not meet the necessary requirements (fig. 5a). The heating of steel to temperatures above the definite point (above the B.Chernov point) normalizes steel behaviour since at this point the additional intergrain bounderies disappear (fig.5b).

Valuable results could be obtained by the employment of radioactive isotopes in the study of diffusion mechanism. Thus far the research into this important question has been very limited. The study of the Kirkendall effect and also the research into the reguliarities of the defect formation in the metal crystal lattice only in a small measure fill the gap in this field.

Research should be started into the influence of high pressures and tension stress upon diffusion in monocrystal and polycrystal alloys.

The employment of the microscope in metallurgy has made it possible to make exceedingly important progress in the study of metal properties and in the testing of its quality. It was determined that metals and alloys consist of separate tiny crystals. The concentration of elements along the borders of these crystals and at times even within the crystals, differs greatly from the average composition of the alloy, i.e. as a rule the alloys are most heterogeneous in their microvolumes. However, the microscope often fails to determine the pattern of element distribution in alloy microvolumes. This task, in many cases, may be successfully solved by radioactive isotopes, namely by the so-called imprint method (autoradiography). The essence of this method is that under definite conditions a metal plate with a radioactive isotope of the controlled element is superimposed on a photo-film. After a certain exposure and development of the film it shows a definite pattern corresponding to the distribution of the element in the metal. The pattern of the element distribution in the alloys can be obtained by the autoradiography method by introducing the radioactive isotope in the metal during its smelting or by subjecting the metal to radiation in atomic piles. In all these cases we find new opportunities compared with the previously known methods (metalography and the local physico-chemical method). The point is that the achievements of nuclear physics enable us to obtain the pattern of element distribution in alloys at an exceedingly low concentration.

The autoradiography method was used in important research work and extensive data has been accumulated on the redistribution of elements in steels and alloys during heat treatment and rolling. Certain details of processes determining the nature of the fracture and the friability of steels have been discovered. The method of autoradiography has been used to study the distribution of phosphorus, sulphur, carbon and tungsten in steels. It has been shown that phosphorus, sulphur and carbon enrich the regions between the dendrite axes (fig.6). It was found that hot deformation and the diffusion annealing cause the dissappearance of a number of elements; this has helped to introduce certain changes into the technology of steel treatment.

It has been determined in a number of studies that the admixtures in titanium and zirconium are situated in a very peculiar way. In titanium samples, slowly cooled from high temperatures, the calcium admixtures are distributed along the bounderies of separate grains and within the grains along the borders separating the crystals of α phase (fig.7). This shows that calcium is a surface active element in relation to titanium.

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It follows that by using the method of autoradiography it is possible to determine the behaviour of an element as regards the distribution in the intra-bounderies in the crystals originating during phase transition and plastic deformation. In particular, of great practical interest is the study of element distribution in zirconium alloys which are characteristic of phase transitions. It has been determined of late, for instance, that small admixtures of carbon in circonium ($\sim$ 0.02%) are distributed most unevenly. In this case carbon is situated mainly along the bounderies of separate grains of the martensite alpha-phase (fig.8). As has been already noted this pattern of carbon distribution in zirconium may substantially reduce the heat and corrosion resistance of zirconium alloys.

Autoradiography has been used on a large scale. In future it is necessary to concentrate upon the improvement of methods for quantitative appreciation of element concentration and upon the development of neutron autoradiography.

New data on the state of atoms in solid solutions may be provided by research into the transfer of dissolved elements under the influence of an electrical field, the employment of neutron structural analysis and also by the study of the properties of alloys subjected to irradiation by nuclear particles.

The study of the movement of atoms in solids under the influence of an electrical field entails a number of difficulties. To a certain extent this is caused by the necessity of high accuracy determination of slight changes in the concentration of the dissolved elements which are caused by the influence of the electrical field. The task of the qualitative study of the transfer in solids may be settled by the employment of radioactive indicators.

Of late the radioactive C^{14} isotope was used to study the transfer of carbon in iron and nickel. The number of the transfer, i.e. the number which describes the value of the current caused by ion movement was determined by the change in the concentration by the anode and catode areas of the sample, occurring along the edges of a narrow radioactive strip on the sample as a result of heating and application of a direct current (see fig.9). This method helps to preclude the diffusion influence upon the transfer and to determine the value of the ionic charge.

It has been shown that in iron, nickel and in the solid solutions iron-nickel, iron-chrome, iron-cilicon, iron-manganese and nickel-chrome, the carbon atoms are in a state of cations. The carbon-ion charges have been determined. The calculations have shown that a charge of carbon-cations for alpha-iron is approximately double charge of carbon-cations for nickel.

The alloying of iron and nickel by certain elements materially changes the cation charge of the dissolved carbon (see table 3). The introduction into pure metals, of elements which differ from the basic metal as regards the structure of the electronic shells and the distribution of the electronic density entails the alteration of the ionization degree of carbon atoms. Thus, in the alpha-iron alloyed by cilicon and nickel the cation charge decreases while during the alloying of iron by chrome no changes in the cation charge are observed. The charge of carbon cations increases when chrome is introduced in nickel.

Table 3

Cation charges of carbon dissolved in iron and nickel alloys

No.No.	Alloy	Charge value
1.	Iron (alpha-phase)	4
2.	Iron-nickel (2%)	2
3.	Iron-manganese (2%)	3
4.	Iron-silicon (3.6%)	2
5.	Nickel	2
6.	Nickel-chrome (4.6%)	4

Data on carbon transfer in iron and nickel alloys help to make certain conclusions regarding the interaction of iron atoms and alloying elements. For instance, the decrease in the charge of carbon cations during the alloying of iron by silicon and nickel may be explained by the transition of electrodes from the atoms of these elements to the atoms of iron.

Valuable information on intra-atomic reciprocity is offered by the study of metal and alloy sublimation. In these experiments the basic moment is the determination of vapour tension by the amount of sublimated substance, which is in equilibrium with the solid phase at different temperatures. The majority of metals and alloys are characteristic of low vapour tension values. Therefore, it is expedient to use for this purpose the radioactive isotopes and the mass-spectrum analysis. It has been proved that by using this method the sublimation of the iron group metals may be studied. The mass-spectrum analysis helps to study the structure of the gaseous phase particles.

As to the results obtained by the study of metal sublimation the following data deserves attention: namely the data describing the influence of alloying and of the structural factor upon the vapour tension value and the sublimation heat. It has been determined that the change in the austenite structure is accompanied by the change in the value of the iron vapour tension.

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The employment of nuclear physics is not restricted to radioactive isotopes. Most promising, for instance, is the employment of neutron radiation. Substantial results have been obtained in the study of nuclear radiation influence upon the properties of solids. Great development has been made in the investigation of the atomic-molecular structure of liquids and solids by the neutron-structural analysis.

The study of the electron structure of the transition element atoms is also a promising sphere for neutronography. All this is closely associated with the peculiarity of neutrons that when they are delivered to a solid body they are scattered by the nuclei of atoms and not by the electrons as γ-rays.

Study has been made of the monocrystals of alloys. This method has made it possible to increase appreciably the accuracy of the method and to employ it for investigation of atomic regulation in iron-nickel alloys of the Permalloy class. Experiments have been also carried out for the determination of carbon atoms position in gamma-iron.

The essence of neutron radiation influence upon the properties of solids is mainly reflected in the atomic displacement from the state of equilibrium. As a result of this, microscopic areas originate in a solid body with an atom arrangement differing from the ordinary and predetermining the alteration of their properties. When metals are subjected to irradiation by powerful fluxes of neutrons we observe the alteration of such properties as durability, plasticity, hardness, electrical resistance. Steel tensile strength may increase by more then 50% and the metal structure may also be altered by subjecting the steel to neutron radiation. It has been shown that neutron radiation may appreciably alter the kinetics of the martensite transformation in the iron-nickel-manganese alloys. The significance of these results is apparent for metalography and for other departments of solid state physics, and, in particular, for the problem of transistors (semi-conductors).

2. Employment of isotopes and nuclear radiation in the iron and steel industry

The output of pig iron and steel is expected to increase substantially in our country in the nearest years. These tasks of iron and steel output may be solved with bigger success if achievements of modern physics are widely employed and, particularly, by the employment of radioactive isotopes and nuclear radiation. We shall now briefly review the state and prospects of certain investigations and studies covering the control of metallurgical processes by methods of radiometry.

The employment of radioactive isotopes for the study and control of pig iron smelting and for the control of the operations of certain aggregates of blast furnaces was started in our country in 1950 on the initiative of Academician I.P. Bardin. At present isotopes are being used in pig iron industry at a number of plants in the USSR.

At several iron and steel enterprises in the Soviet Union research is being conducted into the control of the cycle of the materials which enter the blast furnaces. The data concerning the movement of the batch materials in a blast furnace are necessary for the elaboration of a rational profile of the furnace and for designing more modern blast furnaces. The study of the movement of the batch materials throughout the blast furnace beginning from the charge hole to the hearth and, particularly, the determination of the velocity of movement of certain component parts of the blast furnace charge enables us to get a better idea of the tuyeres' operation.

Formerly, the movement of the batch materials in the furnace was studied by various indirect methods. Literature presents descriptions of experiments on the determination of the velocity of movement of the charge materials in a small section of the upper part of the furnace in the interval between the delivery into the furnace of two charges, one following the other. In these experiments the movement of separate layers of the batch was judged by the velocity of the movement of a load suspended on a steel rope. This method enables us to obtain only qualitative data on the nature of the batch material movement.

The presence of radioactive isotopes of elements comprising the principal parts of the blast furnace batch helps to observe the movement of the materials in the blast furnaces by a method which is new in principle. This method is founded on the principle that one of the pieces of the charge materials is "tagged" by an artificially radioactive isotope. The movement of the chosen material may be observed with the help of radiation detectors or by measuring the radioactivity of the smelting yield.

The tagging of the materials is carried out by different methods. In the most simple case a hole is bored in some granules of the loaded materials and a certain amount ($\sim$10 mc) of radioactive isotopes is inserted. Then the opening is closed by a plug of the same material. Another method of tagging the material is founded on the introduction of radioactive isotopes into the coke of the aglomerate. The third and the most expedient method consists in the activation of batch material granules in nuclear piles. By means of the latter method it is possible to activate the batch materials of the necessary content which is of particular importance in the case of ore which can hardly be obtained synthetically.

At present, two private methods are used to study the movement of the materials in a blast furnace, both of which are founded on the employment of isotopes. By means of the first method we determine the overall time of batch presence in the furnace beginning from loading and to arrival to the hearth and dissolving in pig iron. In this case the materials are charged into the furnace in the area of the charge hole sometime prior to the release of the pig iron. This method does not require any special equipment but it does not give an opportunity of determining the velocity of the batch descent at certain parts of the blast furnace.

The second method requires special equipment: research platforms fixed on the furnace, water cooled coaxial pipes, winches for lowering the pipes with the counters into the furnace, and the necessary wiring for telemetric measurements. The diagram of this experiment is shown in fig.10. In the upper part you see the vertical cross-section of the furnace and below, the plan of the furnace. Radioactive isotopes were introduced on the Ist horizon at a given distance from the centre of the furnace. Radiometric sounding borers were introduced at the horizons: II, III, IV, V and VI. A sounding bore is a combination of three coaxial pipes with water cooling to maintain a temperature of 40° (not more) in the central pipe. The central pipe is closed from the end which is lowered into the furnace and is hermetically sealed. The radiation detector is inserted in this pipe. The self-extinguishing counters were used for the detector. By means of a change-over switch a detector placed at any of the studied horizons may be switched on to the radiometre.

The radioactivity during the movement of tagged granules of the batch from the upper horizon is subsequently recorded at lower horizons. The velocity of the movement in certain parts of the furnace is determined either by the time interval between the radiation peaks corresponding to the passage of the granules through the two neighbouring horizons or by the rate of intensity increase at every horizon. These methods were used for experiments on the movement of the material in furnaces of different volume. The experiments proved that the velocity of the aglomerate movement in the proximity of the central zone of the furnace is in some places higher than in the periphery. It was determined that there is a layer of slow moving materials in the area of the climax and in the lower part of the furnace is below the factual by approximately 15%. Hence, the rectification of the profile of the given furnace in the area of the boshes should result in the increase of the efficient volume. The employment of the new method has also helped to determine the trajectories of movement of separate components of the batch.

The method of radioactive insertions has been used at a number of plants to control the wear of the hearth bottom and shaft lining of the blast furnaces. The study of the climax in the hearth bottom has proved that the bottoms of similar design wear at approximately the same rate.

The climax depth a and the time service t for one of the furnaces are related by the equation $t = 3.19 \exp(2.07a)$. The comparison of the rate of wear of the hearth bottom of furnaces at different plants has shown that the greatest durability is presented by the cylindrical wells and with refrigerators along the territory of the lower part. The wells of a truncated cone shape have inferior cooling conditions and therefore are destroyed more rapidly.

The observation over the state of the lower part of the well may be also made by another method. In this case radioactive cobalt is placed into the lower brick rows of the well while a radioactive counter is put into the thermocouple canal. The lower source is subject to double observation: the radiation intensity is measured by means of the counter placed in the foundation, and the pig iron is subjected to radiometric control as well.

At certain plants radioactive isotopes are being used to control the climax of the heat resistant lining of the blast furnace shaft and of the mixer.

The problem concerning the velocity and direction of the gas flow movement is of substantial interest for the theory and practice of blast furnace operation. Experiments on the determination of the velocity of gas movement in a blast furnace have been made in Britain and in the USSR with the use of radon - a radioactive gas. This method has a number of shortcomings and apparently will not be used widely. Firstly, radon is very dear and the necessary equipment is most complicated. Of late, a method has been worked out to study the gas movement by means of a mass-spectrometre. This method has substantial advantages compared with the methods described in literature. It employs non-radioactive inert gases and the analysis of the gases is conducted by a mass-spectrometre. Thanks to the insignificant cost of ordinary inert gases as compared to radon, this method might find large scale application for control purposes in the iron and steel industry.

At present, a new method is being worked out to control the charge level in blast furnaces. The method is founded on the radiation absorption by batch materials. A closed source of radioactive cobalt is placed in the heat resistant lining of the furnace at the place of the highest level of batch materials loading (see fig.11). Several halogen counters are installed into the lining. The cables from the counters are brought to the measuring instruments stand and are switched in the recorder on a special panel. The detectors are placed in four horizons, three detectors in each. When the charge level descends below the horizon of one of the detectors, the radiation intensity of the detector increases radically and a corresponding signal lamp flares up on the panel. This method makes it possible to determine not only the place of the charge level, but also its deviation from the horizontal plane.

A radiometric method has been worked out for automatic recording of coke density which is charged into the blast furnace. The method is based on the measuring of the absorption of radioactivity by the coke which is supplied to the charging machine. The intensity of the radiation which passes through the coke is automatically recorded. The continuous control of coke density is necessary for timely alteration of the furnace operation in keeping with the changes of the coke density, thereby contributing to the efficience of the blast furnace and does away with unnecessary coke expenditure. This method is of particular interest since it gives the possibillity of automatizing coke charging.

Radioactive isotopes are widely used for studying steel smelting processes. In this field the research has been concentrated on the thermodynamics of the reactions of interaction between the molten iron and slags, on the thermodynamic properties of element solutions in liquid iron, on the kinetics of the transfer of admixtures from the metal to the slag and the kinetics of isotope exchange, and on the phenomena of transfer in melted slags.

Many of the published works have been devoted to the study of the thermodynamics of the distribution of phosphorus, sulphur and chrome among the iron and slags of various composition. Two different methods were used for this purpose. The first consists in the introduction into the molted iron of the radioactive isotope element the distribution of which had to be studied. Slag of a definite composition was placed on the surface of the liquid metal at a constant temperature. The distribution coefficient was determined by measuring the radioactivity of metal and slag samples. One of the important advantages of radioactive isotope employment consists of the possibility of studying the distribution of elements between the metal and slag at very low concentration when chemical analysis does not guarantee reliable results.

The peculiarity of the second method is that radioactive isotopes are inserted into slags of different content in advance. During the smelting in the protective atmosphere small quantities of slag containing radioactive isotopes were consequently added to the surface of the liquid metal. The slag was melted, then it reacted with the metal and left the sphere of reaction. In this process the metal becomes radioactive. The measuring of the radioactivity of metal samples taken after every addition of slag helped to make a more accurate determination of the equilibrium element concentration in the metal under a given slag.

Regular research into slags of a wide composition range have enabled us to find, for the first time, a number of thermodynamic values describing the distribution of phosphorus, sulphur and chrome among iron and slag, depending on the composition and temperature. We have reliably established the values of temperatures of transition of phosphorus, sulphur and chrome from iron into ferrous slag. These processes are characteristic of thermal effects of 50, 12 and 40 Kcal/ gr atom, respectively.

It has been found that the presence of silica in slags alters the temperature of dephosphorization and desulfurization and simultaneously decreases the entropy change during these reactions.

An original method has been worked out for the determination of sulfur thermodynamic activity in liquid iron. The method is based on measuring heat resistant plates radioactivity which are subjected to contact with metal containing sulfur enriched by its radioactive isotope. This method was used to determine sulfur activity change in iron depending on the content of carbon, silicon and phosphorus. On the basis of the obtained data a theory was developed for the metalloid solutions in liquid iron, in the supposition that the dissolved substance forms with the liquid iron both the solution of incorporation and the solution of substitution.

Radioactive isotopes are being effectively employed to study the thermodynamic properties of the solutions of sulfur, phosphorus, chrome, silicon and other elements, in liquid iron. This is effected by measuring the saturated vapour tension of elements over liquid metal at different temperatures and concentration. The vapour tension was determined by the rate of evaporation in the vacuum. By this method a number of values were found (free energy, heat content and entropy) which are of interest for the theory and practice of steel smelting.

The study of the kinetics of phosphorus and sulfur transition from metal into slag is important for the development of methods of obtaining pig iron and steel with the lowest possible concentrations of these harmful admixtures. The employment of radioactive isotopes in this case proved to be particularly expedient. The investigations helped us to find the kinetic equations describing the dephosphorization and desulfurization of pig iron and steel and to determine the factors upon which the rate of metal purification from admixtures depends. It was shown that the most efficient method is to remove sulfur not from steel but from liquid pig iron. We have succeeded in obtaining pig iron with very low amounts of sulfur, of the order of 10^{-4}% both in laboratory and in semi-industrial conditions. It has been also determined that the kinetics of sulfur transfer from pig iron into blast furnace-type slags is described by the equation for the reactions of the first order (related to sulfur concentration in the metal). The study of pig iron purification from sulfur by means of sodium has shown that this reagent is used to a greater extent when the interaction temperature is low.

To study the temperature dependence of the rate of pig iron desulfurization by blast furnace-type slags special methods were used the peculiarity of which is that simultaneous pig iron smelting under slags of four different compositions was conducted in one graphite block. The measurings help to obtain reliable data on the temperature dependence of desulfurization rate. The presence of the restricting diffusion link in the process of sulfur removal from pig iron into slag was corroborated.

The study of the regularities of iron transition from metal into slag and vice versa in the process of desulfurization was made with a view to obtaining data on the mechanism of the process. It was found that the transfer of sulfur from metal to slag is accompanied by iron transfer. The dependence was determined between the above mentioned process upon sulfur concentration of the metals.

Of great theoretical and practical interest is the discovery of the link which limits the rate of reactions in the two-phase metal-slag system. With this purpose a study was made of the kinetic isotope exchange by iron, when the metal and slag are in a thermodynamic equilibrium. In this research we have used the radioactive isotope Fe-59 which was in advance put into the slag. It was found that in the reaction of iron isotope exchange between the slag and liquid metal the slowest link was the diffusion in slag phase or, of mixing took place, the process of mass transfer in that phase. The study of the exchange and the distribution of iron between slag and the steel bath in factory conditions has helped to determine the pattern of the exchange reaction on the basis of the concepts about the diffusion restricting link. The employment of radioactive isotope of iron was used to study the kinetics of iron oxydation during the blowing of sulfide fusion by a blast with different oxygen concentration. Radioactive sulfur was used to study sulfur oxydation from steel during its blasting by oxygen. A study was also made of the tungsten distribution between metal, slag and the gas phase. The employment of radioactive silver has helped to find the causes of pipe cleavage and scab spoilage and to work out effective measures for waste control.

The study in recent years has shown that the prevailing type of bond in the melted metallurgical slags is the ionic bond. Important data on the structure of these fusions may be offered by measuring the ion transfer number. The employment of radioactive isotopes has helped to elaborate a method of determination of the number of transfer, founded on the measuring of very small changes in the concentrations in the fusions which originate when small amounts of electricity are sent through them. It was found that in liquid silicates and phosphates the transfer of electricity is carried out by cations exclusively. The measuring of the cation transfer number in the fusions with two cations, has made it possible to determine the relative cation mobility. Substantial progress has been made by technological study into steel smelting, effected with the help of radioactive indicators. The production of steel with a minimum content of nonmetallic inclusions is one of the basic tasks of high quality metallurgy. In order to settle this problem it is necessary to install such sources which would deliver nonmetallic inclusions into liquid steel during its smelting and pouring. At a number of plants when this question was studied by means of radioactive isotope of calcium the lining of casting ladles, runners, the sifon store and slag were tagged by the radioactive isotope of calcium.

The consequent separation of inclusions from the finished steel and the measuring of their radioactivity give direct quantitative understanding of metal pollution sources. It was found that the pollution of ball-bearing steel occurs only in an insignificant degree as a result of the scouring of the refractory materials and that it apparently depends, in a greater measure, on the secondary oxydation during casting. The study of the nature of slag inclusions in the boiling steel has shown that they originate as a result of drawing into the metal the slag which flows on its surface in the chill, and also due to the scouring of sifon runners. These results have made it possible to work out technological measures which have reduced the amount of spoilage (waste) substantially.

To determine the question concerning the degree to which sulfur which is present in mazut or in gaseous fuel, pollutes steel during its casting in an open hearth furnace, radioactive sulfur was used at a number of plants. This isotope was either dissolved in mazut or was added to the coke-blast furnace gas, and in the course of smelting, samples of metal and slag were taken. The measuring of the radioactivity of sulfur extracted from these samples helps to make a quantitative appreciation of steel pollution degree by fuel sulfur at different smelting stages. It has been determined that during the initial heating and smelting in the open hearth furnaces, depending on the technology used at different plants, from 10 to 20% of sulfur contained in the fuel, transfers into the metal. During the intensive boiling of the metal and during the finishing period, only small amounts of sulfur which is in the furnace, transfers into the metal. The employment of oxygen for fuel combustion reduces the time of metal smelting and facilitates the production of steel with a lower sulfur content.

The study of the hydrodynamic states of liquid phases in the bath of the open hearth furnace is of practical interest since it is immediately connected with heat exchange in the steel bath; with the surfacing of nonmetallic inclusions, the dissolving of alloying inclusions and degazation. The processes of mass-transfer in open hearth furnaces have heretofore being studied by indirect methods only. At a number of plants to study the mixing of liquid steel radioactive isotopes were used as indicators which are fully preserved in the metallic phase under the smelting conditions. The isotopes were set in the furnace floor. The rate of metal movement was appreciated by measuring the radioactivity of metal samples taken from the surface of the steel bath. Fig. 12 shows the kinetic curves obtained in the study for one of the smeltings which indicate the distribution of radioactive cobalt in a 350 ton steel bath of an open hearth furnace. The results of this study have proved that the movement of metals at great rates of carbon oxydation is of a turbulent nature. The experimental data which were obtained have made it possible to appreciate the coefficients of the turbulent diffusion for liquid steel the values of which vary within the range from 400- 1000 cm^2/ sec.

The quantitative relation was found between the values of turbulent diffusion coefficients and the carbon oxydation rate. The results are being used in industry and have helped to reduce the smelting time for certain grades of steel by 19 or 20 minutes. The economical effect of the introduction of the results of this investigation, at one iron and steel combine alone was expressed in a 75,000 ton increase in metal smelting and in saving approximately one million rubles. Radioactive chrome was used to determine the time necessary for the even distribution of ferrochrome in the metal bath during steel alloying by chrome. It turned out that chrome concentration remains uneven in different parts of the bath for a long time and the leveling out of the concentration is achieved only when steel is poured from the furnace.

The method of isotope dilution was used to determine the scrap melting speed and the rate of slag formation in open hearth furnaces. In the first case, radioactive cobalt was introduced into liquid iron which was poured into the open hearth furnace and the radiation intensity of the samples taken from it was measured. The indications of the sample radioactivity taken from the open hearth furnace were used as the measure of weight increase of the liquid metal bath as a result of scrap melting. To study the rate of slag formation from friable materials loaded on the furnace floor, radioactive calcium was used. This isotope, in the form of calcium oxyde was introduced into the liquid slag in the furnace. The drop in the radioactivity of slag samples which were taken during the melting period was used to determine the increase in the slag weight owing to the surfacing of slag forming materials which melted on the furnace floor. Thus, the kinetics of the scrap melting and of slag formation was studied in relation to different technological parametres. It turned out that one and the same equation describes both processes. According to this equation the rate of smelting and of slag formation are proportional to the weight of the hard scrap or lime, respectively to 2/3 degree. A study was also made of the metal charge melting rate in the blast furnaces in relation to the sequence of loading.

Radioactive isotopes were used to study the steel crystalization kinetics in the chill with a view to the determination of the rate of movement of the solid phase boundary in the freezing steel and to determine the influence of crystalization rate upon the nature of element distribution in the ingot. The location of the solid phase boundary was determined by means of consequent additions of radioactive isotopes of phosphorus which are dissolved in steel and which were introduced into steel while it was freezing in the chill. The determination of the radioactivity of metal samples which were inserted at different horizons of the ingot, and also the radio sounding of the templets give a clear picture of metal zones polluted by a corresponding radioactive addition.

This work has shown that the rate of "crust" growth at every horizon is approximately governed by the law of "square root" of time since the contact of liquid steel with the chill. An important conclusion of this work was that the degree of element seggregation in steel is basically determined by the rate of heat release and by the related crystalization rate.

In a similar way the boundaries of the liquid phase in the crystalizing billet were determined during continuous casting. It was shown that the liquid phase boundaries on billet horizons depend on the profile and the size of the billet, on the drawing speed and the intensity of secondary cooling. It was also found out that the distance from the crystallizer to the point of cutting at the maximum cross-section of the ingot and the casting rate of 1.5 m/min. should be 12 m.

Work has been started of late to apply radioactive isotopes for express analysis and for the verification of the accuracy of the chemical analysis methods. The express method has been worked out for the determination of phosphorus pentoxide in slags during phosphorus reduction. The method is founded on the introduction of a small amount of radioactive phosphorus into pig iron. The content of phosphorus pentoxide in the slag is found by measuring the intensity of radiation of slag samples taken from the furnace. A method has been worked out for express determination of tungsten in steel, based on the measuring of the intensity of the flow of electrons reflected from the metal.

The method of trace atoms is used in nonferrous metallurgy as well. The method is used to study the physical and chemical process of hydro-metallurgy, pyro-metallurgy and nonferrous ore dressing. Thus, the trace atom method is used to study lead refining. The study of silver and gold behaviour during crude copper electrolysis has prompted the way to prevent incomplete silver and gold sedimentation into electrolysis slime. The trace atoms are used to study the annealing of concentrates in the "boiling layer" and the method of radioactive indicators is used to study the diffusion in bauxites and nepheline. The latter method is also used for the determination of technology for obtaining super pure aluminium, and to study the interaction of titanium tetrachloride and magnesium. The employment of radioactive isotopes has made it possible to develop the method of a continuous control of metal yield. Formerly this important indicator was determined most rarely owing to the complexity of the experiment. The trace atom method is used to study the dressing processes of nonferrous ores and the mechanism of floatation reagents.

3. Machinebuilding and some other industries

The development of machinebuilding requires the elaboration of effective means of study and control of the wear of parts of various machines.

Much has been achieved along these lines thanks to the employment of radioactive isotopes and nuclear radiation. At present the methods of irradiating in nuclear piles and the method of radioactive insets are used for controlling and studying the wear of parts of hydroaggregates and internal combustion engines. The method of electrolytic activation of parts is also finding wide application.

The control of the initial stages of the run-in of the piston rings is an important study. In this case the control is accomplished by determining the radioactivity of the lubricant in the circulation system, the radioactivity which it acquires during the wear of the rings and the radioactive inserts in them. In this way the necessary run in regime is chosen, reducing substantially the burnishing time and ensuring greater wear resistance after the engine has been worked in.

The dust which comes to the cylinders of the engine with the air and which causes the abrasive wear of the cylinder surface, of the pistons, valves, rings and crankshafts is one of the basic factors affecting the durability of an automobile, tractor or aircraft engine. All sorts of air cleaners are used to decrease the dust impact on the durability of the engine. However, the modern methods of testing the air cleaners require much time, do not guarantee accurate results and are inaplicable to air cleaners which operate on variable regimes. Ordinarily the final conclusion on the usefulness of a certain design of an air cleaner may be made only after a lengthy test of the engine under road conditions (scores and thousands of kilometres). The employment of radioactive isotopes for the settlement of these tasks greatly reduces the time element involved and substantially increases the accuracy of the results.

Special appliances, the so-called dosimeters have been designed for quick testing of air cleaners. These dosimeters are based on the employment of radioactive isotopes. The principle of operation consists in feeding radioactive dust to the air cleaner wherefrom the air comes to a dust collector with a special appliance for measuring dust radioactivity. The efficiency of the air cleaners is determined by the value of radioactivity in the dust collector. It was thus established that the operation of air cleaners is less effective when the engine works in a pulse regime.

Of great importance for machinebuilding are also the following questions: the determination of the contact area of the friction surface, the determination of the influence of the lubrication film thickness on the wear of the metal, the study of the physico-chemical interaction of the lubricant with the friction surface, the control of the wear of cutting instruments, etc. The employment of radioactive isotopes solves many of the indicated questions in a comparatively simple way.

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Experience has shown that the use of the method of radioactive indicators in the sphere of engineering is most fruitful and at times irreplaceable due to its exceedingly high sensitivity and thanks to the possibility of continuous recording of diverse processes which describe the operation of the machines.

The method of radioactive core sampling by electrical means to study the geological cross-section of holes has become particularly wide-spread in prospecting work, particularly for oil prospecting and extraction. Rocks possess natural radioactivity of various intensity. Therefore, the measuring of the intensity of the natural gamma-radiation by instruments suspended into a hole offer a characteristic of the geological cross-section of the drill hole. Besides, it is also possible to artificially increase the radioactivity of rock by treating it with salt solutions activated by radioactive isotopes. The pumping of activated liquid into the drill hole makes it possible to easily distinguish the permeable layers of the rock. These layers partially absorb the activated solution and as a result their radioactivity radically differs from the other layers.

By means of radioactive isotopes the pipeless communication of liquid between the layers in the exploitation and delivery holes may be studied, the places of spoilage in the drive pipes may be determined, the zones of clay mortar discharge may be ascertained, the results of hydraulic rupture of the layers are controlled, the water and oil bearing layers are detected, and the exact location of the oil-bearing layers is ascertained. Thanks to the similarity of the physical and chemical properties between the tritium and ordinary water it proved to be possible to use tritium water as an indicator in the study of water streams at oil fields, etc. One of the modifications of gamma core sampling is the neutron gamma core sampling by means of which the gamma radiation of rock is measured. This radiation originates under the influence of a neutron emitter lowered into the hole together with the recorder. As distinct from other methods of core sampling the radioactive method may be used in holes equipped with drive pipes and thereby it may be used for the determination of the cross-sections of old holes. Radioactive core sampling is successfully used on new areas where the methods of core sampling by electrical means are not very efficient.

A geophysical method for coal prospecting has been elaborated. The method is founded on the observation of the intensity of radioactive cobalt scattered gamma radiation. A method is being elaborated for the determination of the industrial content of heavy metals (lead, mercury, tungsten) in the cross-sections of drill holes by means of selenium-75 which emits soft gamma rays.

The ionizing influence of the radiation is also widely used for the solution of various problems. Under the influence of radioactive emissions gases and liquids are ionized.

This property of radioactive isotopes presents substantial interest for industrial use. The air ionized by radioactive iradiation becomes electro-conductive which is important for combatting the static electricity charges in the production of artificial fibre, in the textile, film, paper, rubber, oil and printing industries.

The introduction of new types of synthetic fibre and rubber, the increase in machine speed at textile mills and other industries where dielectrics are machined is associated with the accumulation on the machined material of substantial electro-static charges which cause technological waste and are dangerous since they are liable to entail fires and explosions. The increase in loom speed at textile mills is restricted due to big electro-static charges which originate on silk. The neutralisation of these charges by sulfur-35 made it possible to increase the speed of looms 2.5-fold. At one of the camera-film factories, electro-static charges of the order of scores of thousands of volts originate on the moving material and entail great technological waste and regular inflamations. By installing plates with radioactive polonium-210 over the moving material, the electrical charges were swiftly removed thereby eliminating spoilage and inflamation of the film. At a glass fibre factory the grease was washed off from the glass fibre in benzine and in the process there took place an accumulation of electro-static charges up to 55000 volt. The charges were continuously causing the inflamation of benzine and therefore the production had to be suspended. When plates with the isotope of thallium-204 were installed over the moving material the inflamation of benzine was terminated.

These experiments prove that an installation made of metal plates with small amounts of alpha or beta emitter coating on them helps to fully eliminate the harmful consequences of static electricity. It should be noted that the effectiveness of radio isotopes in combatting static electricity has been described in foreign literature.

Most promising are the works associated with the employment of radioactive radiation for industrial gas purification. By ionizing the waste industrial gases by radioactive radiation the coagulation and consequent separation of tiniest fractions of dust from the gas can be brought about. Thereby new opportunities are opening up for the utilisation of dust and for improving the atmosphere both at enterprises and in communities. It is most desirable to have "prepared" gases for active chemical interaction by converting neutral molecules into ions. This is particularly necessary for the intensification of numerous industrial operations.

According to American data the gas ionization effect may be used for the analysis of gaseous binary mixtures. Two electrodes are placed into the analyzed gas medium which had been treated by irradiation and then voltage is applied.

An ionic current originates and its increase is measured by a recording device. The most suitable for gas analyzers is beta emitter-stroncium-90. Alpha and gamma emitters are unsuitable for this purpose since the former have a small permeability while the latter yield a small ionization effect.

Foreign literature scribes experiments into the possibilities of applying radiation for the improvement of properties of adhesives and adhesive insulation tape. Radioactive isotopes are also used in the production of dyes which were difficult for synthetic production formerly. New types of heat resistant glass are developed with the use of radioactive isotope methods. Radioactive isotopes are used at cellulose factories for controlling the cellulose mixing with other chemicals, etc.

A research has been carried out into the opportunities of employing gamma radiation to obtain anti-freeze rubber. Silicone rubbers founded on polydimethyloxane and other similar rubbers have high heat resistance and low temperature of vitrification, in this respect they are superior to other known rubbers. However, their potentially high anti-freeze qualities (vitrification temperature -109, -129°) is practically not used at all since at temperatures from -40 to -45° these rubbers lose elasticity due to crystalization and even chemical vulcanization fails to prevent the crystalization of silicones. Radioactive treatment of silicones has helped to completely suppress crystalization and preserve the elasticity of rubber. Hard rubber with frost-resistance up to -125° was obtained.

There has been a report in foreign literature that dimethyl silicones are subject to rapid vulcanization under the influence of high energy radiation. The radiative vulcanization according to this report has a number of advantages compared with the usual chemical vulcanization. Cobalt-60 and other radioactive isotopes obtained in nuclear reactors may be used as the emittors. There is another report about experiments for increasing the diesel fuel caloricity by means of radioactive coal. 5% of fine graded and irradiated coal dust was added to oil. The irradiated materials increase the combustion rate which means that the size of the engines may be smaller. The radiation of the radioactive isotope placed into the engine's combustion chamber increases the fuel combustion rate by 59%.

The "Atomnaya Energia" (Atomic Energy) journal has reported that the USSR research institute of canning industry is making experiments of radiation sterilization and pasterization of foodstuffs by subjecting them to swift electron and gamma-ray irradiation. Fresh meat sterilized by irradiation has been preserved for 12 months and is not losing its main taste qualities. In Britain and in the United States research is conducted into the employment of radio-activity for the sterilization of foodstuffs. Cesium-137 and sodium-24 (from waste heat producing elements of atomic reactors) and neutron activated indium are used for these purposes.

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There are reports indicating that radiation sterilization alters the taste of the foodstuffs which is probably entailed by the influence of free radicals which originate during water radiolysis, upon food components. The conference held in Cambridge on September 26-27, 1957, devoted to the problems of food irradiation arrived at a conclusion that irradiated products should be withheld from the consumers for several years.

Research into food irradiation has been conducted for about two years in the United States. Gamma radiation was widely used and most promising results were obtained during the irradiation of bacon, green peas, peaches. The products were preserved after radiation treatment for 12 months at a temperature of 22°. The study of radiation treatment influence has been also made on pork, chicken, mutton, liver, cox fillet, carrots, cabbage, lemons and oranges. Bacon, roast beef, veal, beefsteaks, porkchops, mutton chops treated by irradiation of 2 mln. rad. were recognized as suitable for consumption by more than 100 experts, although some of the products had an after-taste and a rather abnormal smell. Radio pasterization of fresh products has helped to double and even more than double the term of preservation. The best packing is a white tin can.

IV. Radioactive Isotope employment for flaw detection and industrial control

The opportunities offered by the employment of radioactive isotopes for purposes of control and automation of production processes are vast and most varied. Many experimental models of diverse instruments based on radio isotope employment have been designed at Soviet organisations. In our country serial production is conducted of many types of instruments based on radio isotopes, including: radioactive UR-6 tank gauge, radioactive RPU-1 indicator of liquid level, radioactive MIR-2 ionization manometre and radioactive liquid sensimeter of the PGR type. In 1957 an explosion-proof tank gauge of the RSU-1 was designed, as well as a radioactive ionization manometer of the MIR-3a, a stationery tank gauge of the RSU-m type, a remote level control radioactive signal indicator of the DRSU-2 type and a beta spectrometer. A certain number of instruments employing radioactive isotopes are being manufactured by instrument making enterprises of the oil industry, of the geological, ferrous and nonferrous metallurgy and by other organizations.

Radioactive isotopes are employed for flaw detection and control. The gamma flaw detection photo-method is used at many iron and steel mills. The objects of control are diverse cast and welded goods, parts and units of metallurgical, conveying, hoisting and auxiliary equipment. Thus, the method is used for checking the weld seams of blast furnace shaft housings, weld seams of big capacity pouring ladles, cast billets, weld seams of locomotive boilers and other items. For purposes of radioscopy artificial isotopes of cobalt-60 and iridium-192, cesium-137 and other isotopes are used.

Besides the photographic method of gamma flaw detection an ionization method of flaw detection has been also developed in the USSR. At present an ionization flaw detector designed for weld seam control in high pressure pipes of 650mm diameter (see fig.13) has passed factory trials. The sensitivity of the ionization method control is approximately equal to the sensitivity during radioscope while the productivity of the former method is increased several scores of times.

Radioactive isotopes are widely used in instruments for controlling production processes in iron and steel industry. At present the main fields where these instruments are used include the measuring of the thickness of rolled sheet metal in rolling, the measuring of tin coating thickness in blanching and also the automatic control of liquid metal level in crystallizers and in pouring installations of continuous casting. Several types of radioactive thickness gauges are being manufactured in the USSR. These gauges operate on beta radiation for measuring small thicknesses or coatings and on gamma radiation for medium and big thickness measuring.

The employment of radioactive isotopes offers an opportunity of measuring the level of friable and liquid bodies in a container without introducing in it a transducer. This makes it possible to regulate the level of materials in ore hoppers, in containers with aggressive liquids and substances at high temperature and pressure. A radioactive emitter is installed outside the container on one of its sides and on the other side the counting tube with an amplifier. The amplifier has a switch-over relay on the output to switch on the executive mechanism which effects the level control.

One of the first Soviet tank gauges with the employment of radioactive isotopes is the UR-4 tank gauge. However, it was not designed for operation in aggressive external medium. At present 20 tank gauges are being manufactured for nonferrous metallurgy and for operation in particularly aggressive mediums. These will measure the liquid level in containers from 1.6 to 6 m. A portable tank gauge has been also designed for the determination of the level of liquefied gases in sealed containers. Tank gauges are used for controlling the level of crushed stone in hoppers, the level of hot bitumen, hot nitric acid, mixtures of liquids at high temperatures and pressures and also for the determination of the boundaries in several mediums.

In semi-continuous and continuous casting of steel and nonferrous metals it is of paramount importance to maintain a definite metal level in the crystallizers and it is also desirable to have an automatic relation between the metal level in the crystallizers and the mechanism regulating the speed of ingot drawing. Radioactive instruments for controlling steel level in crystallizers of continuous casting machines are being improved.

Gamma rays may be used for measuring the density of liquid and friable substances in tanks and pipe lines. For these purposes cobalt-60 or cesium-137 are used. Radioactive pulp densimeters were used in the work of section dredges. At present an instrument is being designed for the determination of pulp density for the needs of the nonferrous dressing mills. Another instrument is based on this principle and is designed for the determination of the specific weight of the agglomerate and of heat resistant materials. The method of measuring the density of material by gamma ray absorption has been used for the construction of a number of other instruments. Thus, there is an instrument which makes it possible to control the quality of coke supplied to the blast furnace. The employed coke quality analysis methods practically do not influence the technology since the results of the analysis are supplied with a great delay. The radio isotope instrument measures coke density immediately before charging which makes it possible to regulate the blast furnace operation accordingly with the quality of the coke delivered.

At certain electric stations the radioactive isotopes are used for automatic prevention of breaks in fuel supply (coal dust) from the furnace hoppers. As it happens coal dust gets often clogged in the hoppers and therefore there is a radical drop in steam production by the boilers and a loss in the capacity of the station.

An automatic attachment for a cigarette-making machine controlling the quality of cigarette stuffing was shown in 1957 at an International exhibition. This appliance has two emitters containing stroncium-90. One of them operates for the standard absorber while the second irradiates the cigarette. The tension which originates during the disbalancing of the circuit is supplied to the appliance controlling the cigarette stuffing density.

A substance absorbs radiation proportionally to is mass. This makes it possible to use radioactive isotopes for very accurate thickness measurings. Particularly important is the employment of radioactive isotopes for measuring metal thickness in rolling at modern high speed band rolling mills. Instruments have been designed in the USSR for measuring the steel band during the process of rolling covering thicknesses from 5 to 10 mm by means of thallium -204, cesium-144, iridium-192 and cobalt-60. There are also instruments for measuring the thickness of paper, textile band, of oilcloth, etc.

Instruments have been also designed for the determination of the water resources in snow banks, for the determination of the thickness of pipe and reservoir walls used for operation in aggressive media.

There is a description of instruments to control the quality of zinc steel coating without violating the integrity of the coating. These instruments are based on scattered beta radiation measuring.

They may be used when surface temperature of parts reaches 350°. Radioactive stroncium-90 is used for the emitter. This instrument may be used also for other purposes, for instance, for measuring the microscopic dispersion of lead stabilizer in sheet polyvinylchloride.

Radioactive isotopes may be also used for packing control. The packing of various powders with the employment of appliances based on radioactive isotopes is conducted with a much greater speed than by ordinary weighing. Similar instruments are used in America for packing tooth-paste tubes, for controlling the number of tablets in a package, etc. Ordinarily stroncium-90 is used as the emitter.

Of particular interest is the employment of radioactive isotopes for lighting devices. There are models of atom powered lamps designed for continuous 10 year operation. Gaseous radioactive krypton-35 and crystals of specially prepared phosphorus in a hermetically sealed glass tube are used as a source of light. The radiation of krypton-35 causes the luminescence of the crystals.

There are reports in literature about the employment of isotopes for safety means. Counters are placed in dangerous spots and the operator wears shirt-cuffs supplied by radioactive isotopes. When the operator's hand comes close to the dangerous zone it is recorded by the detector and the machine stops automatically. Moreover, the machine cannot be put into operation until the operator remains in the danger zones. The isotope radiation doze supplied to the shirt-cuff is absolutely harmless for the workers. The radioactivity of the emitter is less than the radioactivity of the luminescent dial of a wrist-watch. In Britain a small size radiometric appliance has been designed to detect an inflamation or fire at a great range. There is a great number of other instances proving the large-scale employment of isotopes and nuclear irradiation in diverse spheres of science and industry.

CONCLUSION

Radioactive isotopes have found a comparatively broad employment in diverse spheres of science and engineering in our country and in foreign countries. However, it cannot be considered that the opportunities of this method have been exhausted. On the contrary the discussed results of certain investigations reveal the necessity of further investigation into effective employment of isotopes and nuclear radiation in science and engineering. One of the first tasks in this field we believe is the employment of reactor activated materials, neutron emitters, short lived radioactive isotopes, mass-spectrum method and also special research into various radiometric transducers for controlling appliances.

Particular attention must be devoted to the development of research into radiation physics and neutronography.

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ILLUSTRATIONS

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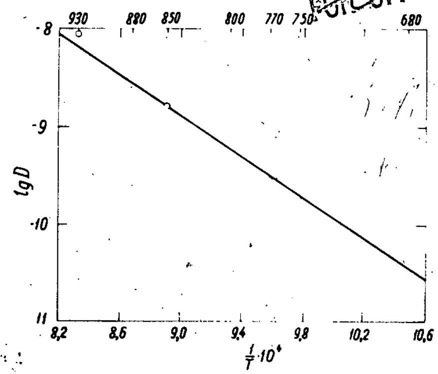
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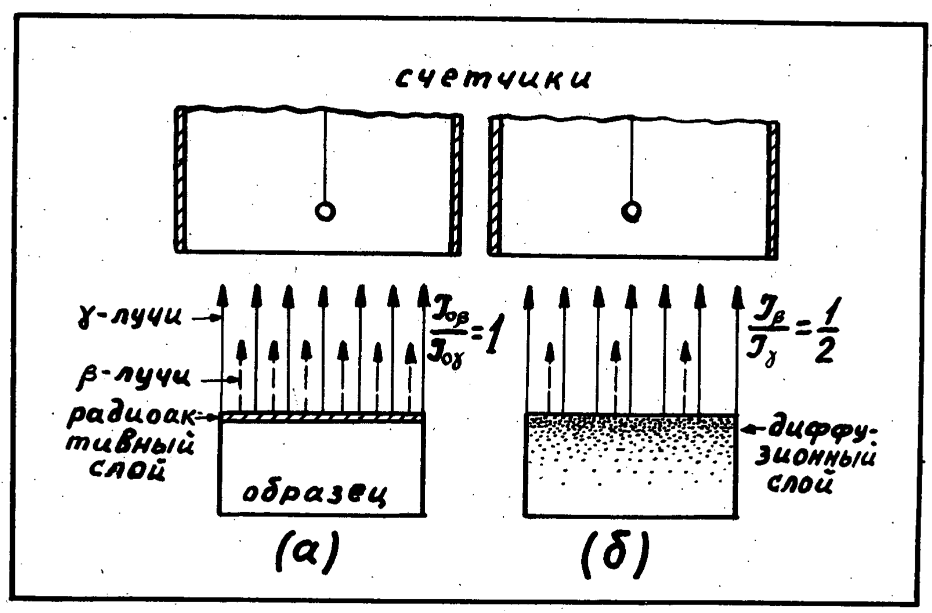
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γ-лучи
β-лучи
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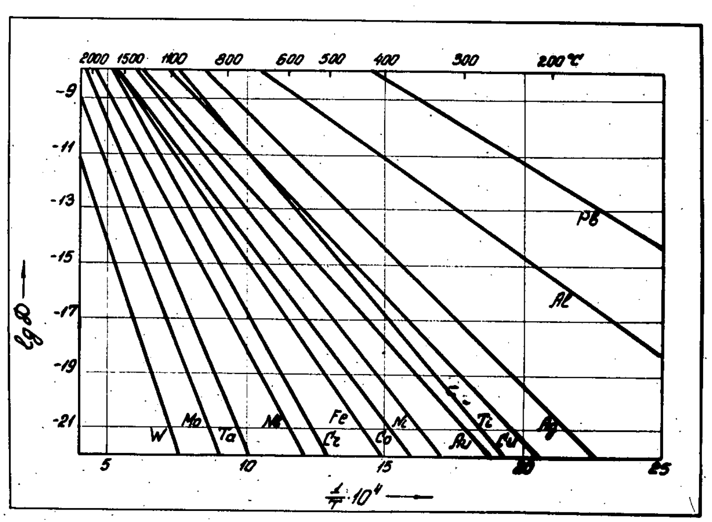
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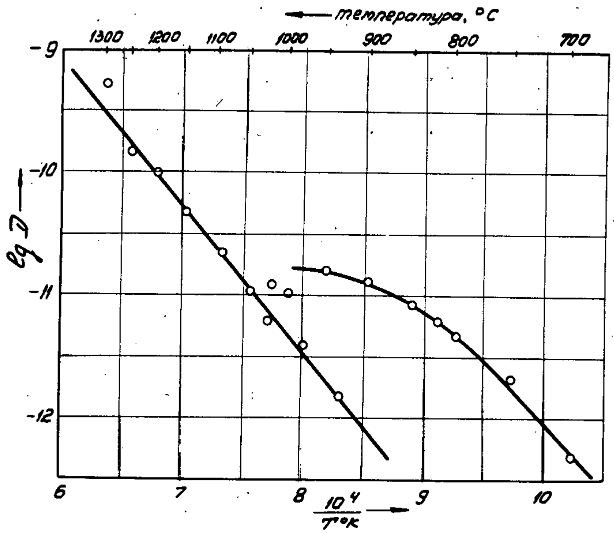

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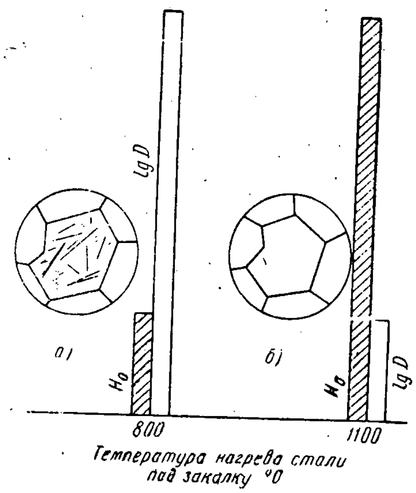

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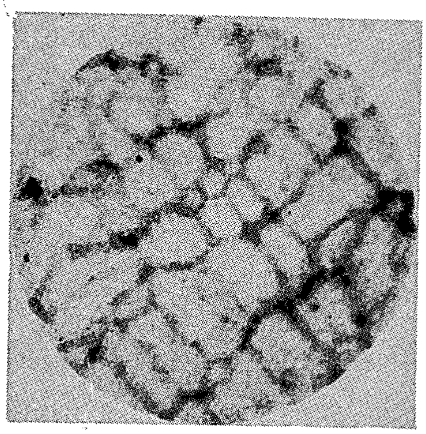

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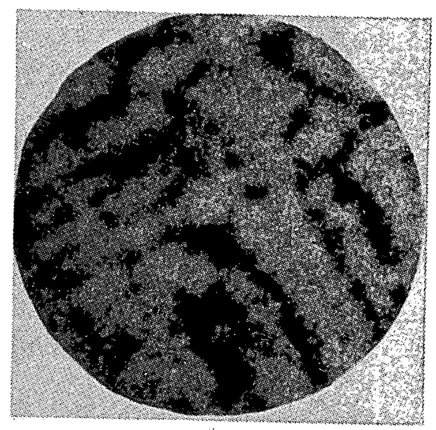

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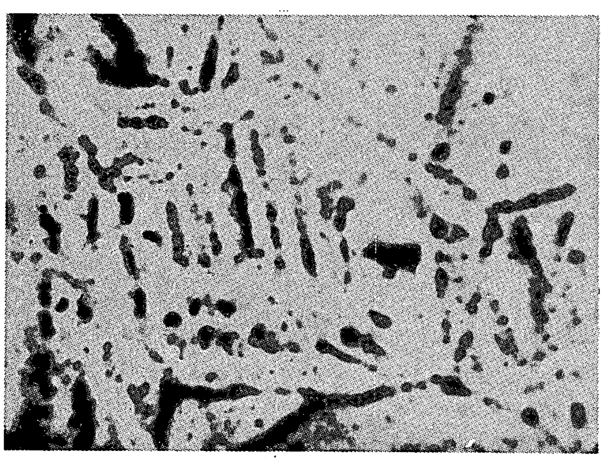

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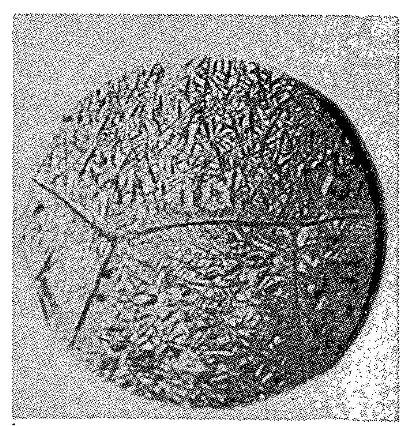

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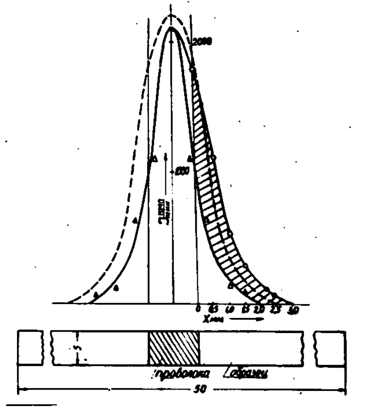
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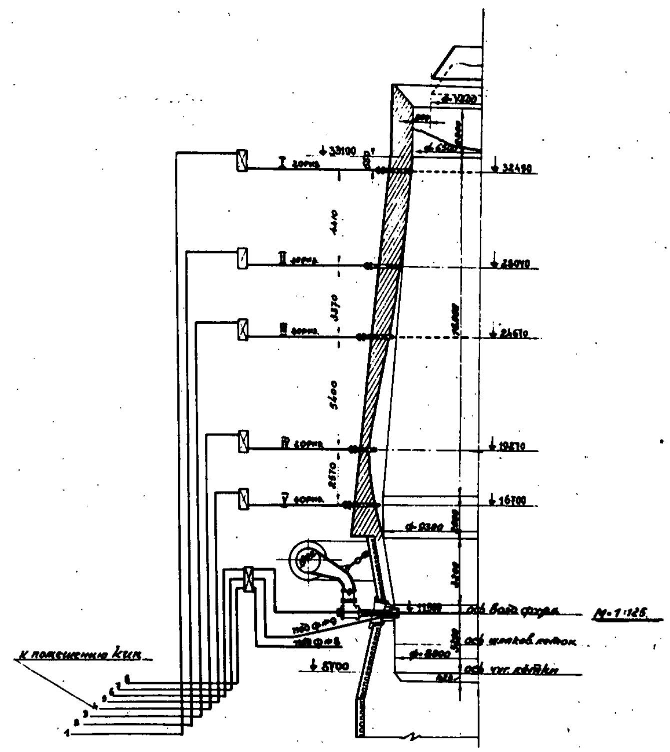

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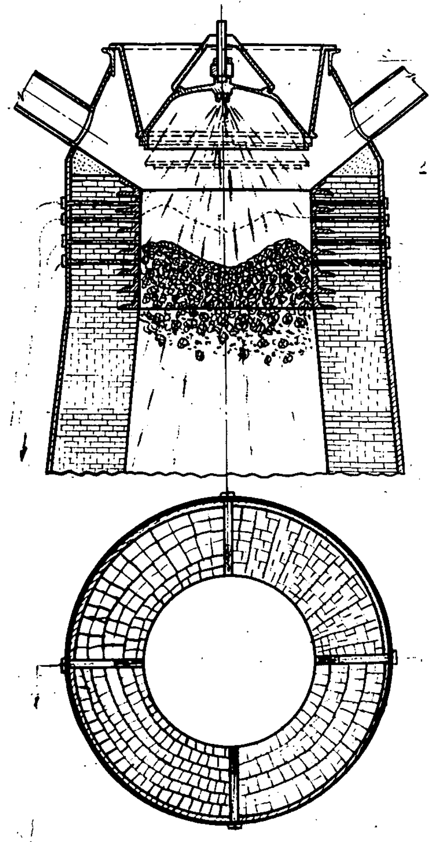

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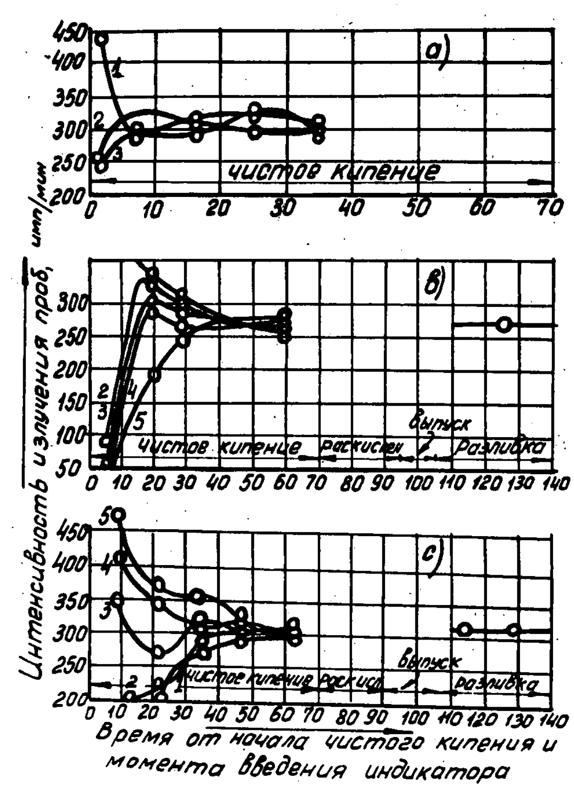
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Выпуск
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разливка
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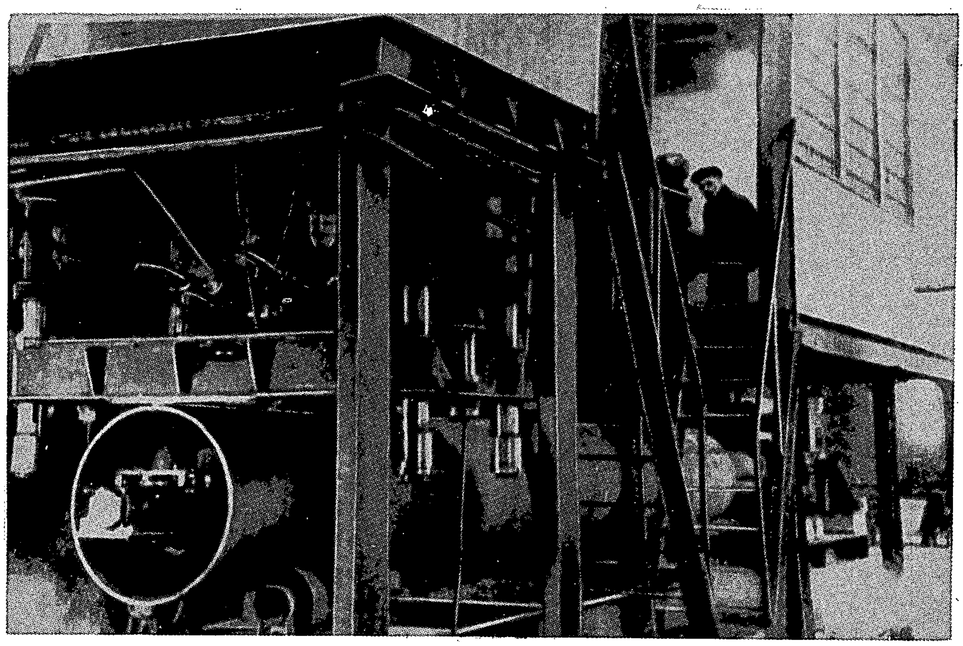

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RADIOACTIVE FALLOUTS AND THEIR CONSEQUENCES FOR HUMANITY

By Prof. A.V. Lebedinsky

It is difficult at present to point to a scientific topic, which would attract such a close attention of the researchers and the cultural community at large as the problem of ionizing radiation and its biological effects.

The reason for this lies, of course, in the extremely interesting scope of questions related to this problem. Indeed, studying the effects of ionizing radiation on living bodies allows to take a new look at a number of life events, discloses new ways of scientific approach to the most intractable phenomena. During the process of these studies it became possible to find new prospects for applying radiation to treatment of some diseases that practically do not lend themselves to conventional methods of treating. And, lastly, the up-to-date knowledge on biological effects of radiation appeared necessary to provide an answer to the urgent problem that unexpectedly and acutely faced the mankind. It is a question of what experimental nuclear and thermonuclear explosions may mean to people. The stark reality of scientific facts forces us to admit that our surroundings have undergone substantial physical changes as a result of nuclear tests.

These changes are due to the fact that the natural background radiation, which is always present in the atmosphere, has risen owing to radioactive fission products being released and incorporated into the living organisms.

It naturally leads one to ask wheather it may have any consequences for the living beings that inhabit our planet. If science admits that the raising of this problem is justified, it appears that there is a need to appraise the nature of these consequences. In case they are considered hazardous it will be necessary to make an appraisal of the danger and concentrate the human efforts to control it. A short summary of the contemporary data characterising the present state of affairs will come within the scope of this paper.

It should be first emphasized that the problems touched by us have already been widely dealt with elsewhere in literature. A great number of newspaper and magazine articles as well as a series of specially published books have been devoted to the "radiation hazard" problem. Among the latter of particular interest are the following: "Nuclear Explosions" published in India at the suggestion of Mr. J. Nehru (1956), a Parliamentary Report by the British Medical Research Council (1956), a report by the National Academy of Sciences and the National Research Council of the United States (1956). Apart from these official publications which are the outcome of work by large groups of scientists, a mention can be made of the following books:

"Radiation, What It Is and How It Strikes You" by Schubert and Lapp (Great Britain) and "Radioactive Hazards" with the preface by Bertran Russel (Great Britain, 1957). Thus, one is to conclude that the problem of possible effects of nuclear tests has been not only raised, but is being most actively discussed by the most authoritative scientific establishments in various countries of the world as well as by a number of scientists. One proof for the anxiety due to the radiation hazard is the discussion of the problem at the 10th General Assembly Session of the United Nations (1955) which decided to set up a special Scientific Committee on Atomic Radiation, and whose activities are participated by scientists from 15 countries, including those from the USSR, Czechoslovakia, the USA, Great Britain, France, Belgium, India, Egypt and a number of other countries. The aims of the Committee include studying the radiation level operative on the human being and also obtaining information on its effects upon man and his environment. In July of this year the Committee is to report to the XIII Session of the General Assembly. It is common knowledge that on the initiative of the Government of Czechoslovakia the XII Session of the General Assembly discussed the question of radiation effects on humanity (1957). It is known from the Session's materials that mainly due to the efforts of the US delegation this problem, which is vital to all mankind, was not discussed as it should have been, and the decision on it was suspended until the Scientific Committee on Radiation presents, to the XIII Session, a report which is now under preparation (1958).

In order to give an explanation to possible consequences of the increased background one must be reminded of what this background is and what are the changes in its value that had already occured.

A human being living on the Earth's surface is being constantly exposed to the naturally occurring radiation which is composed of the two major sources--external and internal. In its turn the external background radiation is determined by the activity of cosmic rays, the radiation from the Earth's surface and the materials used in the building of human residences and that from the radioactive gases of radon and thoron that occur in the surrounding air (the atmospheric source). The internal irradiation results from the presence in our body of radioactive isotops of potassium, carbon and radioactive gases (in the bloodstream and other body fluids) as well as from the radium fixed in the bone tissue. The total natural radiation background is responsible for a dose received by a man which is equivalent to that received while exposed to X-rays at a rate of 100 milliroentgens a year. A dose due to the radium exposure has been neglected here.

At the present time it is a well known fact that experimental nuclear explosions increased the amount of natural background both in the external and internal ranges of exposure of animal and human bodies.

The nuclear reaction taking place during the atomic blast continues for a portion of a microsecond being a momentary starting point for successive events. In a few seconds there appears an unusually shaped mushroom cloud containing the fragments of nuclear fission products that are carried high upwards to an altitude of 30 or more thousand metres above the Earth's surface. The wind streams break this cloud apart and initiate a chain of events, which last for many years, sometimes decades and, perhaps, even longer.

Once the cloud is set in motion it takes a few minutes for the fallout to begin. The locality of the fallout is governed by wind direction and speed. This is a so-called <u>local fallout</u> settling down at a distance of hundreds kilometres from the blast centre. It was this that caused the radiation injury of the 23 Japanese fishermen aboard the vessel "Lucky Dragon" at that ill-fated daybreak of March 1, 1954, when the US Armed Forces exploded a hydrogen bomb at the Bikini atoll.

Smaller particles of radioactive dust carried into the troposphere are drifting in the prevalent air streams and fall to the Earth's surface as rain, fog or snow. This kind of troposphere radioactive fallout can be deposited on the ground during a month or more after the explosion time contaminating more or less the area around the world at a latitude where the explosion took place.

Lastly, the lightest particles of radioactive products, then in the stratosphere, are distributed over the whole area of the Earth. The stratosphere accumulates a supply of radioactive products which gradually shift into the troposphere from where, still in the form of fallout, they precipitate everywhere on the ground and water areas of the world for 5 to 10 years following the blast.

The nuclear and thermonuclear explosions lead to a great amount of radioactive products being released by the fission of the atomic nuclei. Their overwhelming majority belongs to the short-lived radioactive isotopes.

In the general estimate of the radiation danger due to test explosions it is required that account is taken of all its three sources of origin--fallout within close reach, troposphere fallout and radioactive substances slowly shifting down from the stratosphere.

As far as the first source is concerned, there is a well-known evidence of the radiation damage done to the residents of Nagasaki and Hiroshima in 1945, of the above mentioned disease of the Japanese fishermen, inhabitants of the Marshall Islands and of some American servicemen in March, 1954, which were caused by a local radioactive fallout.

The danger involved in the troposphere fallout is often underestimated. If one rules out the possibility of injurious effect from the short-lived elements, which have time to desintegrate before the arrival of a cloud at some locality of the world, it appears nevertheless that the snow- and rain-carried radioactivity can be large enough, especially if there is a considerable precipitation at the given place, and bursts follow one another within a short interval of time. It may be accompanied by:
1) the γ radiation effect from the soil covered with this kind of fallout; 2) feeding of animals on grass and eating by man of vegetables and fruits, that contain the radioactive products deposited on them; 3) the transfer into the human organism of the milk from animals which were fed on the "radioactive" food and 4) the direct penetration of radioactive particles in the human body with the air being breathed in.

To appraise the biological consequences of the troposphere fallout one is required first of all to differentiate between the short-lived and long-lived radioactive isotopes.

Certainly, the short-half-life isotopes are responsible for a casual effect, which is governed by a number of factors and, by the way, by the time elapsed since the time of explosion and the isotope half-life. For instance, J^{131}, that has the half-life period of 8 days, can succeed, during the period it is active, to spread great distances from the seat of explosion, to fall out and to enter the aninal and human organisms.

The "casual" exposure, as we have termed the radioactive effects due to the tropospheric fallout, can constitute a definite hazard as a result of frequently repeated nuclear blasts. We will show further that some vital living systems accumulate the rayage received by them.

The long-half-life radioactive isotopes originating during nuclear explosions are the ones that therefore attract most attention; they include Sr^{90}, Cs^{137}, and Pt^{239} arranged in the order of their biological effects. The half-life periods of these radioactive isotopes are 19.9, 33 and 24.000 years respectively. Once the problem of the nature of changes that have taken place in the physical properties of the human environment has been raised, we should regard these radioactive isotopes with a great care. Apparently, once on the Earth's surface they will continue active for a long period. But this is not all. Being placed in the stratosphere, the radioactive isotopes will for a long time be a long-term supply source for the ground-surface radioactive fallout. If the United States and Great Britain follow the example of the peace-loving nations of the USSR and stop tests in 1958, the amount of the above mentioned radioactive isotopes at the surface of the Earth continues to grow during the next

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years owing to the "supplies" stored by the stratosphere. This process would have inevitably proceeded for the further 10 to 15 years until the equilibrium set in, i.e. the state at which the quantity of newly deposited radioactive products makes up for the loss of the radioactive products deposited previously. After the equilibrium is reached i.e. a certain maximum, there will be a restoration process proceeding in the physical environment of the Earth inhabitants.

It will be quite another thing if the tests are not discontinued. Corresponding estimates have been made at present for Sr^{90}. Of course it is no easy task to forecast the rate of future tests and the size of bombs to be exploded. But if one considers that the Sr^{90} quantity released by the explosion will be the same as in 1954-1957 tests, the equilibrium state can be expected only at the turn of the century. According to the data provided by Japanese physicists, to every square kilometre area there will be the strontium-90 activity of 320 mC. It means that since 1952 on the living beings of the Earth have begun to exist for the indefinite future in physically altered environmental conditions, the degree of these changes in the natural radiation level increasing everywhere in a fatal and inevitable manner.

At the present time several hundreds of special observation stations operate all over the world, measuring systematically the fallout, there are also scientific institutions engaged in radiochemical analysis of the soil, food products and human bones. The results of these investigations show that 1) there is a general increase in the earth γ-irradiation due to Cs^{137} fallouts; 2) the upper soil layers contain radioactive strontium activity of 6 to 20 mC/sq.km, the greater values being detected in the northern hemisphere; 3) food products both of animal and vegetable origin as well as drinking water contain Sr^{90} and Cs^{137}; 4) the presence of radioactive isotopes is discovered in the human body.

Proceeding from the fact that radioactive isotopes penetrate the human body, while some of them (Sr^{90} and Pt^{238}) are deposited and fixed there, one has to admit that changes occur not only in the physical conditions of environment but inside the organism as well. Thus, there is an increased irradiation dosage received not only due to the external source, but from the internal radioactivity too. Sr^{90} ranks high among the various internal irradiation sources.

Strontium-90 which deposits on the Earth's surface is a well soluble compound. Therefore the uptake of this radioactive isotope by plants is easy due to which it becomes an initial link in the biological chain of events.

In addition to Sr^{90}, that enters the plant life from soil, the latter can contain extra quantities of this radioactive isotope via the rainout.

The further strontium-90 migration towards the human organism is along two paths, On the one hand it enters the organism in association with vegetable food products, on the other hand it chooses a more complex route, the animal organism providing the intermediate stage. In this case the Sr^{90} in the vegetable food finds its way into the animal organism, becomes a component of milk, is incorporated later in the milk products and penetrates the human organism.

Fish and fish products provide additional access for Sr^{90} to the human organism. It concerns mostly the fresh water fish, the body of which can concentrate considerable amounts of Sr^{90} as a fallout on the water surface. Thus, this radioactive isotope resulting inevitably from the nuclear and thermonuclear weapon tests is distributed over the whole area of the world and invading the food chains gets its way into the human organism. As we will see later, as a result of its metabolism peculiarities in the organism Sr^{90} is fixed there for a long time. A situation arises when the human organism as if collects the Sr^{90} deposited on the ground and water areas and cumulates this radioactive isotope.

The stable strontium is a necessary chemical element component of the human organism. The adult person skeleton contains 7 grammes of this element. The strontium metabolic activity in the bone tissue is a very slow process. Due to its disintegration, Sr^{90} is a source of ß-irradiation. Together with the stable strontium and calcium upon its entry into the bone cells it exposes them to irradiation affecting in the same way the blood producing organ cells--the bone marrow cells in the cavities of the bone tissue.

Since Sr^{90} is being fixed in the bone tissue at length, while under modern conditions there occurs a constant acquiring of the substance by the organism, the amount of this radioactive isotope in bones is growing gradually.

Numerous bone analyses made at the various points of the world disclosed the presence of radioactive strontium. Investigations of this kind revealed a number of significant facts.

Firstly, strontium-90 is detected everywhere. On every continent of the world wherever the samples were taken for investigation one has inevitably come across the fact of Sr^{90} being present in the bone tissue structure.

Secondly, the Sr^{90} content in the bone tissue is growing constantly, year in and year out. For example, according to the information given by American researchers W.R. Eckelmann, I.L. Kulp and A.K. Schubert, the number of strontium units in the bones of children aged 0 to 4 years who were born in New York and Boston was 0.28 in 1953-54, 0.57 in 1954-55, 0.61 in 1955 and 0.69 in 1955.

Thirdly, in several instances considerable departures from the average values are recorded. For example, in 1955-56 samples were encountered that had a content of 1.6 to 2.0 strontium units (USA and Switzerland). This natural scattering of values forces one to concede the existence of individual peculiarities resulting in an increase of strontium in the bone tissue by a factor of 3 and maybe more as compared with the "average" results. This fact should be borne in mind in considering the obvious increased strontium content in bone and appraising the biological effects of the process.

It should be emphasized that despite the general character of strontium-90 fallout the inhabitants of different areas of the world face the strontium menace under different circumstances.

The fallout in the Northern Hemisphere is greater than that in the Southern. Weather irregularities, particularly greater, precipitation at the same geographical location, lead to greater radioactive strontium fallout. Lastly, the nature of the human food ration is a condition of extreme significance, that controls the non-uniform character of the Sr^{90} accumulation by the organism, other things being equal. A series of calculation shows that with the vegetable products predominating in the diet (Japan, for example) one can anticipate twice as much strontium in bones as under conditions of milk products based diet.

While comparing the available data, an indisputable conclusion can be arrived at to the effect that from the start of nuclear and thermonuclear tests and onwards there have been, are and will be changes occurring in the environmental conditions of man as well as inside his organism due to the greater exposure to ionizing radiation. It must be emphasized that these occurrences are not justified by any humane reason. Quite on the contrary, the tests undertaken have the aim of improving the mass destruction weapons. The consequences of the tests involving a certain degree of risk for the mankind cannot be escaped by the community inhabiting the world. No one has a free choice as regards the possibility of avoiding or suffering the danger, although every person may be aware of its implications and scale due to the modern science findings.

It must be said that representatives of science made an open and timely statement on the radiation hazards. It is sufficient to make a mention of the statement delivered by more than 9.000 scientists, that was handed over to the UN General Secretary and which carried a demand to stop test explosions.

What is the matter? What is worrying scientists so much, who soberly take stock of the likely consequences from the nuclear and thermonuclear tests?

Of course, it is the undisputed fact that these tests make the possibility of nuclear warfare more feasible. But a well-grounded anxiety is also being bred by the experiment aftereffects. In order to obtain an understanding of their nature it is necessary to take an effort and look into the biological changes both inside and outside a human being, of which we made mention before.

These changes are accounted for by radiation exposure at low dose rates, i.e. at those which do not cause an immediate death of organisms and do not lead to the early developing changes in its life activity. One may assume that they are of a more perfidious nature, being detected after a long time since this factor was operative. The possibility of this long-range effect places an especial responsibility on the present political figures until the scale of radiation hazards becomes extreme.

At present there are no grounds for doubting the biological activity of small doses. It is a proved fact that some strains of lysogenous bacteria being exposed to X-rays at the rate of 0.1 roentgen have given clear indication of changes in their biological properties (Marcovitch H. 1958). There are also data testifying to the fact that a transient lymphocyte count decrease occurs in the peripheral blood of a man exposed to radiation of 16 to 60 milliroentgens (M.Wakabayashi 1958). In 1957 the Japanese scientist K. Motokawa discovered that exposure to a few milliroentgens causes recognisible threshold changes in the sensitivity of the human eye to electric current (the formation of the so-called electric phosphene). But it is not these phenomena that are of interest for us in estimating the hazard of radiation which is composed of the three main factors: i.e., firstly--the possible disturbances in development processes, secondly--the somatic consequences in the form of leukosis and malignant tumours or bone sarcoma; and thirdly--the so-called genetic consequences which mean an influence on the human heredity.

We may anticipate the disturbances in development processes on the basis of our knowledge of Sr^{90} depositing in foetus bones. It is established now that the depositing of radioactive strontium in the foetus skeleton begins at an uterine stage. The process takes place at a time when the size of bone cavities, housing the embryo's central nervous system, are so small that beta-particles emitted from the cranium and vertebra bones undergoing formation, can easily penetrate into the cerebrum and spinal cord. Minimum doses which are already damaging to the nervous system have not yet been estimated. However, as it was found in experiments with animals, the foetuses whose females had received strontium prior to pregnancy have shown, after birth, disturbances in the functions of their nervous system. The appearance of malignant neoplasm is now being linked with the ionization inducing cell mutations. Such somatic mutations may have as one of their final results a leukosis and the malignant growth of bone cells.

We know very little on the nature of cell mutations. Some scientists are of the opinion that this form of cellular reaction to the ionization is thresholdless, which means that its possibility increases with any excess in the level of natural ionization.

The genetic consequences should be regarded as unavoidable under any excess in the natural level radiation exposure. The reaction of especially radiation sensitive formations of hereditary substance concentrated in the chromosomes of sexual cells underlies such consequences.

Quite a few scientists admit that each element of such formations is of an unsubstitutable and unique character and therefore every act of ionization would entail unavoidable, although differing in the degree of their importance, consequences. Once originated, these disruptions are unrestorable, and thus, each of the successive acts of ionization increases disturbances which have been added to those occurred previously.

This leads to infringements in the system of information which is essential for the repetition of hereditary properties. As a result of it the hereditary properties of an individual are impaired and because of the fact that the whole humanity is subject to an increased background of radiation, the deterioration of hereditary properties in the world population becomes inevitable. Thus, we have every reason to predict an increase in the number of hereditary diseases.

No one can deny at present the possibility of menacing consequences of the increased natural background which we have mentioned before. Controversial appears to be the question of minor significance: i.e. how much will be the increase in cases of sarcoma and hereditary diseases--or in other words--whether the number of people who had paid for nuclear tests such a costly price would be great or small. The so-called "arithmetics of death" or a more accurate estimation of this number is of no significance for either prohibition or justification of tests. To prohibit the tests it is enough to admit the feasibility of such like consequences of experimental explosions.

It is stressed sometimes that although there is a potential danger in conducting nuclear tests, the humanity is also subject to other, no less menacing, hazards. One of such is ascribed to consequences of excessive radiation exposure during diagnosing with the help of X-rays. Actually, in some of the technically developed countries X-ray diagnosing totals to a dosage comparable with natural background which exceeds almost 100 times rayage of radioactive strontium already accumulated at present in bones.

But such a comparison is nothing more than an illusion of convincingness. In fact the use of X-rays for diagnostic purposes renders an invaluable service for it not only protects patient's health but very often even his life. The modern engineering achievements permit to limit more and more the dose of exposure necessary for the investigation of patient's illness. On the other hand, test explosions, becoming more powerful and frequent, increase the danger of exterminating large number of people and clear the way for atomic war.

One does not need to mention other arguments employed by the advocates of continuation of nuclear tests, who now have very often to resort to purely political argumentation which has nothing in common with the genuine interests of humanity. Nothing can justify the suppression of elementary freedom i.e. the human desire to live in the natural conditions free from the danger of radiation.

However, we may think that the danger can be averted. It is common knowledge that on March 31, 1958 the Government of the USSR has adopted the unilateral decision to discontinue all tests of nuclear and thermonuclear weapons. By this act the great atomic power embarked on a path which insures satisfaction of the mankind's vital interests. Unfortunately this act of genuine humanism had not yet been imitated on the part of other countries who possess nuclear and thermonuclear weapons. It is essential that the tests be stopped for the continuation of them with every successive explosion increases the danger of radiation the only real way for the elemination of which was shown by the Soviet Government.

(A.V. Lebedinsky)

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RADIOACTIVE ISOTOPES IN BIOLOGY AND MEDICINE

By Professor V. Modestov

The last 25 years have been marked by great discoveries in nuclear physics. In 1934 Joliot and Irene Curie succeeded in splitting the nucleus of the atom by means of nuclear particles and in producing artificially radioactive substances.

A large number of nuclear particles have now been discovered; in the hands of scientists these particles are the weapons by means of which nuclei are split and artificially radioactive substances are obtained.

Radioactive substances make it possible to produce labeled compounds, (i.e., compounds whose composition includes radioactive isotopes) not only of inorganic substances, but also very complex organic compounds, from bacterial cells to toxins.

If radioactive iron is introduced into the organism it will form part of the erythrocytes and the latter will be labeled; radioactive phosphorus introduced into the organism of a chicken will label the white of the eggs they lay because its composition will include radioactive phosphorus; if radioactive phosphorus and methionine labeled with sulphur are introduced into the medium in which a fungus is cultivated the product of disintegration of the fungus--penicillin--will be labeled.

Many examples could be cited in which radioactive isotopes were used for the purpose of producing labeled medicines and the latter were utilized in studying the mechanism of their action on the organism.

The successful utilization of radioactive substances is favoured by the highly developed measuring techniques and the very complex radiometric and dosimetric apparatus which record comminuted radioactive radiations.

Scientists are now directing their minds at the possibility of utilizing the truly inexhaustible resources of intranuclear energy which offers extensive opportunities for the development of science and engineering. It would be difficult to find a branch of natural science or engineering unaffected directly or indirectly by the latest achievements of the physics of the atomic nucleus. The extreme sensitivity of the method of radio active isotopes has made it possible extensively to utilize isotopes in biology and medicine.

The introduction of the method of isotopic indication into laboratory and clinical practice for the study of metabolic processes, utilization of radioactive isotopes for diagnostic purposes and for the treatment of some diseases, etc., all undoubtedly constitute major scientific achievements.

Since the invention of the microscope there has probably been no other method in biology that could compare with the isotopic method by its potentialities, the depth of influence

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on the subject matter of the biological experiment and by the extent to which it has spread.

These achievements have made it possible to study many new problems, including such that until very recently appeared absolutely insoluble.

The use of radioactive isotopes has made it possible to investigate the fates of substances which are of special interest to us from the moment they are introduced into the organism till the time either a labeled substance is eliminated from the organism or its metabolites containing the tracer atoms.

The high sensitivity of the method has enabled us to trace minute quantities of highly toxic and medicinal substances --carbon sulphide, sulphurous gas, hydrogen sulphide, etc.-- in the organism, their distribution through the organs and tissues and their elimination from the organism.

Very interesting data on the distribution of labeled medicinal compounds--bromides, caffeine, aminasine, veronal, novocain, etc.--through divisions of the brain have been obtained. It has been shown that the component parts of the organism are constantly renewed, that the speeds of the processes are characteristic for each process and that they change when these processes are pathologically disturbed.

It has been established that the average lifetime of the brain proteins is 12 days and that the metabolism is more intensive in the grey than in the white matter of the brain. It has been found that the brain is capable of greater resistance to oxygen hunger at low temperatures, which fact is very important to present-day surgery.

The use of radioactive isotopes has made it possible to establish inhibition of nervous activity during narcotic sleep. In this case the proteins, nucleic acid and the phospholipids are renewed at a slower rate, whereas during excitation of nervous activity they are renewed at a faster rate, i.e., their metabolism becomes more intense.

Acetic acid and other fatty acids labeled with radioactive carbon have found wide application in studying the mechanisms of metabolism of fats, phosphatides, stearins and carbohydrates.

It has been shown by means of labeled acetic acid that the carbon dioxide formed in the organism in the process of oxidation can be used in synthetic processes and is not merely an end product of metabolism to be completely eliminated from the organism.

Microelements play an important part in the biochemical processes which ensure the normal vital activity of the organism. These include copper, zinc, cobalt, bromine, etc. Radioisotopes have helped in ascertaining the significance of these microelements in the biochemical processes. For example, the radioactive isotopes of cobalt were used in labeling vitamin B_{12}. With the aid of a sulphur labeled vitamin B_1 it was possible to study the metabolism of this vitamin in the organism.

The isotope of zinc helped in throwing light on the mechanism of the action of insulin--the hormone produced by the pancreas.

The various aspects of mineral metabolism and its disorders in pathological conditions, particularly in rickets, fractures and formations of calluses, were studied with the aid of radioactive calcium and phosphorus. The studies of the biochemical processes in the bone have made it possible to ascertain the conditions under which the consolidation of fractured bones is accelerated and rachitic changes in the bone are eliminated.

Radioactive isotopes have found application as means of research in the solution of such urgent problems as the etiology and pathogenesis of the toxicoses of pregnancy, the nature of the physiological and pathological metabolic processes in pregnant and non-pregnant women, the essence of the exchange processes between the mother and the foetus (permeability of the placental barrier), the mechanism of the action of hormones, vitamines and numerous medicines (particularly, antibiotics and sulphanilamide preparations), etc. It has been established that when radioactive phosphorus, sodium, caffeine, vitamin B_1, streptocide and penicillin are administered to pregnant rabbits these labeled compounds are very soon discovered in the placenta, in various organs and tissues of the foetus and in the amniotic fluid. Contrariwise, when these substances are introduced into the amniotic fluid or directly into the foetus they can be discovered in the mother's blood.

The distribution of labeled penicillin, sulphazole and streptocide through the tissues and organs and their elimination from the organism was observed. It has been found that they are distributed through the organs and tissues evenly.

Microbiology studies the influences of ionizing radiations on pathogens and on immunity. It has been shown that as a result of immunization per os the permeability of the intestinal wall for dysenteric toxins decreases.

Spores of pathogenic and non-pathogenic fungi and of tuberculous bacteria were labeled by means of radioactive iodine. It has been found that the pathogenic fungi accumulate in the reticuloendothelial system (liver and spleen), whereas the non-pathogenic fungi are quickly destroyed in the organism.

Labeled tuberculous bacilli were injected to the guinea pig subcutaneously and their distribution was observed. One hour after their injection large numbers of them could be discovered in regional glands and within two hours in the lungs. Very few tuberculous bacilli were found in the brain tissue.

Not only labeled antigens but also labeled antibodies have been obtained with the aid of radioactive isotopes.
The use of labeled penicillin has made it possible to establish essential differences in the aborption of the antibiotics by the sensitive and stable bacteria.

In connection with the use of radioactive isotopes the theory of the organism's physiological barriers has lately made a big advance. The haematoencephalic barrier was studied in the clinic, and the permeability of the eye, the inner ear, the joints, the skin and the vessels was studied experimentally. The studies of the haematoencephalic barrier in patients suffering from cranial trauma and from arachnoiditis have shown that the barrier was not disturbed in either case; on the other hand, extensive disorders are observed in meningeal symptoms. A comparative appraisal of the organism's barrier adjustments has shown that the haematoencephalic barrier is the strongest and is followed by the haematolabyrinthine, the haematoophthalmic, the placental and, lastly, by the articular barriers. Physiotherapeutic practice has revealed that when labeled medicines are introduced into the organism by means of galvanic current depots are formed at the point of introduction. The distribution of labeled medicines through the organs and tissues, the duration of their stay in the organism and the rate at which certain ions enter the organism have been established. It has been found that by means of direct current it is possible to concentrate medicines at a definite spot and also to remove them from the organism.

Resorption of a haematoma in the abdominal cavity has been studied by means of labeled erythrocytes. It has been found that the greatest number of labeled erythrocytes has entered the blood in the course of 9 to 21 hours. This warrants the assumption that the greater part of the haematoma is resorbed during this period of time.

The foregoing examples show the enormous scope of scientific problems studied with the aid of isotopes. It may be said that the famous "labeled atoms" are "glow-worms" which let us know about themselves from the darkest labyrinths of nature. They help in studying the intimate processes in the human organism.

The radioactive isotopes of elements with a relatively short half-life have lately found particularly wide application in clinical practice.

Radioactive sodium is of clinical interest in determining the rate of the blood flow. It has been established that in healthy people in a state of rest the pulmonary circulation takes 5-6 seconds and the systemic--11 to 13 seconds. Observations have shown that in the second stage of hypertension the blood circulation slows down on an average to 15.3 seconds and in the third stage to 18.4 seconds. The decaleration of circulation during the late stages of hyper-tension is a well-known clinico-diagnostic symptom of latent cardio-vascular insufficiency, which may be of practical importance.

The rate of circulation is studied by means of radio-active sodium also in patients suffering from diseases of the peripheral vascular system. It appears that in these patients the rate of the blood flow is sharply altered. This method is used for determining the rate of the blood flow in the stump and in patients suffering from endarteritis obliterans, arteriosclerotic gangrene, and various spastic conditions.

The determination of the circulatory rate can also be used before and after treatment as an index of the efficacy of various medicines.

Radioactive sodium is also used in the studies of the functional state of the kidneys. Introduced intravenously radioactive sodium is discovered in small quantities in the urine during acute nephritis.

Radioactive iodine has found wide application in the studies of the thyroid function in Soviet medical establishments. The studies of the thyroid function are of great clinical importance for diagnosing the disease of the thyroid gland.

This method is used in a number of pathological conditions: subfebrility of an unclear etiology, cardiovascular diseases, and cardiac decompensation in which the question of removing part of the thyroid gland is often unreasonably raised. The function of the thyroid gland is also studied in tuberculosis. The incipient forms of this disease show increased thyroid activity, whereas during the advanced stages of the disease the function of the thyroid gland is decreased.

An increased function of the thyroid is observed in rheumatism, tonsillitis, a number of cases of psoriasis, poisoning, leucodermia, pregnancy, etc.

Radioactive iodine helps in diagnosing intrathoracic goitre and in establishing whether or not the thyroid gland has been totally removed in cancer of the thyroid; it is also used in diagnosing the metastasis of the thyroid cancer into the lung, liver, bone tissue, etc.

The physicians diagnosing cerebral tumours meet with considerable difficulties. Radioiodine helps here, too. In this case the thyroid gland is first saturated with iodine and then additional doses of radioactive iodine are administered; a little later the radioactivity is measured at different points of the skull. The greater part of iodine is drawn primarily to the tumour. The point of its strongest radiation is fixed and the tumour is located.

A lifetime photograph of the thyroid gland with the aid of radioactive iodine is of considerable interest. The amount of radioactive iodine absorbed by the thyroid can be judged by the extent to which the photoemulsion has darkened.

Radioactive phosphorus is used for diagnostic purposes in clinical practice, especially in determining the disorders of the haematoencephalic barrier in cranial trauma and in other brain diseases.

Radioactive phosphorus is used in diagnosing cancer of the cervix uteri, cancer of the prostate, and cancer and metastases of the mammae.

Labeled erythrocytes are used for the purpose of studying the life cycle of erythrocytes and the mass of circulating blood.

The use of the method of including radioactive phosphorus in the erythrocytes is of considerable importance in a number of diseases (toxicoses) of an infectious or other nature. Observations show that the percentage of radioactive phosphorus included in the erythrocytes varies with the gravity of the disease. Normally this inclusion constitutes 18 - 25 per cent, but the percentage sharply decreases with the gravity of the disease. In tuberculosis it drops to 11-13 per cent and in fulminant tuberculosis to 7-8 per cent.

Radioactive gallium is used for diagnosing the early metastases of cancer into the bone tissue when it is impossible to detect them by means of a radiograph.

Radioactive cobalt is employed in a number of diseases in which the motor-evacuant functions of the stomach are disturbed.

The development of the atomic industry offers wide opportunities for using various radioactive isotopes for therapeutic purposes, mainly in treating malignant tumours.

Malignant tumours are the most redoubtable and unyielding enemy of human health. Man has vanquished many diseases, but cancer and other malignant tumours are still the scourge against which science is as yet unable to do very much.

Surgery, roentgeno- and radiotherapy are as a rule, employed wherever possible in the treatment of malignant tumours.

Of the enormous number of radioactive isotopes known today radioactive cobalt is of the greatest interest as a source of gamma-radiation; this isotope has now almost completely replaced radium and radium mesothorium in the therapy of malignant tumours.

The clinical observations conducted in Soviet oncological establishments on a big number of patients with malignant growths of different forms have revealed certain advantages of radioactive cobalt over roentgen, radium and radium mesothorium, namely: 1) the apparatus is less complicated, 2) it does not require daily doses, 3) the spectrum of radiation is homogeneous, 4) does not form gas like radium and 5) is as efficacious as radium and radium mesothorium and in some cases even superior to them.

It has been found that the changes in the skin and the mucosa during the treatment of malignant growths are less intensive than they are under the same conditions when acted upon by radium and radium mesothorium. It is particularly noticeable in the application method of treatment and is accounted for by the homogeneous radiation of radioactive cobalt (1.17 and 1.33 Mev).

The reactions of the skin, which with the same doses produce symptoms of marked epidermatitis in roentgeno- and radiotherapy, are reduced to erythema or dry epidermitis when irradiated by radiocobalt on gammatherapeutic apparatus. The apparatus may be divided into four groups in accordance with the conditions of work: 1) long-focus therapeutic gamma-apparatus with a cobalt activity of 400 g -eq.R designed for irradiating deeply located foci, 2) short-focus therapeutic gamma-apparatus with a cobalt activity of 20 g -eq.R designed mainly for treating superficially located malignant tumours, 3) apparatus for contact therapy and 4) applicators which are a modification of contact apparatus.

As before stated, threatment by radioactive cobalt was administered to a large number of patients with malignant tumours of the skin, the mucosa of the oral cavity, the tonsils, the upper jaw and nasal cavity, the larynx, the oesophagus, the lungs and the mammae, as well as of patients suffering from cancer of the reproductive system. It was revealed that the direct and remote results of the treatments were in no way inferior to those obtained from the use of natural radioactive substances.

The treatment of a large number of patients suffering from cancer of the eyelid skin resulted in the cure of 94 per cent of the cases with no complications connected with the treatment. The results of the treatment of many patients with various malignant growths in the first, second and third stages obtained with the aid of radioactive cobalt were not only not inferior to those obtained by treatment with natural radioactive substances, but in some localizations there was even a higher percentage of cure. The treatment of tumours of the pharyngeal ring by radium mesothorium resulted in a direct cure of 61 per cent of the patients, whereas treatment by radiocobalt resulted in the cure of 70 per cent of the patients; in cancer of the larynx in the first and second stages treatment by radium resulted in protracted relief in 73 per cent of the cases, whereas in treatment by cobalt brought relief in 82 per cent of the cases.

In the treatment of patients with cancer of the lower lip and with cancer of the skin a cure was effected in 76 per cent of the cases in all four stages.

Radioactive cobalt was used in the treatment of lymphogranulomatosis. Observations have shown that this form of radiation treatment has certain advantages over roentgenotherapy. Roentgen resisting forms of lymphogranulomatosis may undergo reverse development as a result of irradiation by radiocobalt. Gamma-radiations with a high penetrating capacity may be brought to the pathological foci in large doses without injuries to the skin. Lastly, it is necessary to note the more rapid and more complete reverse development of the lymphogranulomas of the lymph nodes and of some other organs owing to which the remission of the disease is prolonged.

Radioactive cobalt is used in the treatment of tuberculous lymphadenitis, According to the data of some authors roentgen irradiation of dense tuberculous lymphatic nodes results in relief in 20 to 65 per cent of the cases, whereas the use of radiocobalt brings relief in 70 to 75 per cent of the cases. The results of treating the hyperplastic form of lymphadenitis by roentgen rays and radiocobalt are apparently equally satisfactory.

Radiocobalt is used in the treatment of capillary angiomas. The results are quite satisfactory. The angiomas pale and the ulcerations heal. It is also widely used in treating patients for inflammatory diseases (paronychias, furunculoses, carbuncles, phlegmons, hydroadenitides, etc.); good results, in no way inferior to roentgenotherapy, have been obtained.

Gamma-therapeutic irradiation is administered to patients suffering from acromegaly and from adiposogenital dystrophy. In these cases the patients are administered combined irradiation of the hypophyseal and hypothalamic region from four fields and the upper cervical sympathetic ganglia with one field on each side of the neck. The results are quite satisfactory in 50 per cent of the cases. The grave symptoms diminish and disappear, vision is restored, the patients return to an active life--to work, which makes radiation therapy effective in an individual approach to the patient.

Radioactive phosphorus has found wide application in the treatment of polycythemias and is deservedly, perhaps, the only method in the therapy of this disease. Until now the treatment of polycythemias aimed to suppress the erythroblastic function of the bone marrow or to accelerate the haemolysis of the erythrocytes of the blood. This is facilitated by the fact that radioactive phosphorus selectively accumulates in greatest quantities and is retained for the longest time in bony tissue.

The considerable accumulation of radioactive phosphorus in the bones and the high radiosensitivity of the rapidly multiplying elements of the bone marrow condition the predominant effect of the radiation on the pathological growth of the bone marrow. Observations of a number of authors on the effectiveness of treating polycythemia by radiophosphorus have shown that in some cases the remission lasts from 12 to 18 years.

The administration of radioactive phosphorus in leukemia has shown the following forms to be indicated in the treatment: 1) chronic myeloleucoses and lympholeucoses, the so-called slow and intermediate forms in the advanced stage of the disease, 2) chronic myeloleucoses and lympholeucoses with a considerably increased spleen (in myeloleucosis and lympholeucosis), and 3) the same forms but with anaemia (in these cases simultaneous administration of erythrocytic serum is particularly recommended).

It has been found that the treatments by radioactive phosphorus are considerably more efficacious for the patients suffering from chronic myeloleucosis and from chronic lympholeucosis if general health-building treatments are administered at the same time, especially, haemotherapy, vitaminotherapy and antibiotic therapy.

In treatment by radioactive phosphorus the remissions last 1.5 to 2 years and in some cases 2.5 years,

Radiation therapy is widely and successfully administered in diseases of the skin of various etiology. In the treatment of skin diseases radioactive phosphorus is administered mainly by external irradiation by means of applicators. It is thus used in the treatment of capillary angiomas. These are one of the varieties of vascular tumours observed quite frequently in both children and adults. The expedience of using radioactive phosphorus is based on the low penetrability of its emanations (up to 8 mm). Considerable relief is obtained in 85 per cent of the cases.

Extensive work has been done in studying the use of radioactive phosphorus for epilation in a fungus disease of the hairy part of the head. It has been found that radioactive phosphorus causes epilation within 12 to 14 days and that hair begins to grow again within 30 days. Regrettably, the treatment produced an early (on the 3rd or 4th day) or late (within 14 to 16 days) reaction of the skin in the form of a slight eythema which has prevented its extensive use in medical practice.

Radioactive phosphorus was used in the treatment of patients with erythemo-squamous dermatitides (eczema, psoriasis, etc). As is well known, eczemas and neurodermatitides are encountered very frequently, take a long course and are attended by attacks of tormenting itch; they are often hard to treat or are not amenable to treatment at all. The use of radioactive phosphorus has yielded good therapeutic effects. In weeping eczemas the weeping ceases, the hyperemia diminishes and epithelization ensues. Even by irradiation with small doses a good therapeutic effect is very rapidly obtained in the treatment of a slowly healing sores. In the treatment of restricted forms of eczema the result was stable in 50 per cent of the cases as observed for a period of 3 years.

Treatment by radiophosphorus was administered for furuncles, carbuncles, hidradenitides, acute and sub-acute forms of thrombophlebitides and inflammatory hemorrhoidal plexes. The dose and frequency of irradiation depend on the character of the process. The results are quite encouraging.

Radioactive phosphorus is used in the treatment of hyperkeratosis of the skin, Bowen's disease and leucoplakia.

Attempts to use radioactive phosphorus for the treatment of herpes have been made and satisfactory results have been obtained.

It may be used for accelerating the consolidation of bone and for the bony transplant to take root. It has been shown that this process takes 45 to 50 days, while without radiophosphorus it takes 140 to 150 days. Traumatic practice makes successful use of catgut impregnated with phosphorus and oxbone nails impregnated with small amounts of radioactive phosphorus for purposes of fixation in fractures. All this expedites the appearance of calluses.

Insoluble salts of radioactive phospho-chromium are used in the treatment of the metastases of malignant tumours. The advantage of using them lies in the possibility of a single administration of the solution which is eliminated from the tissues very slowly.

To prevent relapses and metastases of cancer after the cancerous tumour is excised a fibrin film saturated with radioactive phosphorus is applied; this film melts in the wound.

Radioactive iodine has found very wide use in the treatment of thyrotoxicosis and malignant tumours of the thyroid gland. The observations of many Soviet clinics show that with a properly chosen dosage the administration of radioiodine to patients suffering from hyperthuroidism produces a very good and lasting effect. The principal symptoms of hyperthyroidism--tachycardia, weakness and increased excitability--diminish and disappear. The patients gain weight, the basal metabolism and the size of the thyroid gland come down to normal.

This method of treating thyrotoxicoses is efficacious and may be recommended in all cases when surgical interference is for some reason impossible or when the patient categorically refuses to submit to an operation. Observations have shown that the best results are obtained when radioactive iodine is administered in fractional amounts. Therapeutic practice has shown that in the gravest cases of thyrotoxicosis, when no surgical interference is possible because of the patient's emaciated condition, administration of radioactive iodine gives a large percentage of good results (92 per cent), while the percentage of complications (hyperthroidism) does not exceed 0.9 per cent.

Diffuse goitre should be treated, whereas treating nodular goitre by radioiodine is not recommended because it frequently degenerates into a malignant tumour.

Of late, radioiodine has found wide application in the treatment of metastases of cancer of the thyroid gland because they develop early and very often. According to some authors they are observed in 85 to 90 per cent of all cases. The successful treatment of the malignant tumours of the thyroid gland depends on the extent of absorption of radioactive iodine by the tumour and its metastases, which in its turn depends on the histological structure of the tumours. The studies of a number of authors have established that in most cases radioactive iodine produces a positive effect on the tumour of the thyroid gland and on its metastases.

In our experience with treating the metastases of the thyroid gland in the lungs and bones we have obtained good results. In these cases the radioactive iodine was used with due allowance for its effective half-life.

Radioactive iodine is used in the treatment of stenocardia and in other heart diseases; however, along with positive results it is necessary to mention a big percentage of complications. It is also administered in disorders of cerebral circulation due to sclerosis.

Radioactive strontium 89 and 90 is widely used in treating eye diseases. It is also used in the treatment of superficial tumours: papillomas of the lids and of the conjunctiva, and angiomas of the lids and of the conjunctiva in infants. It is likewise used in the treatment of spring conjunctivitis and in tuberculosis of the anterior segment (chamber) of the eye, for the prevention of vascularization of the cornea and for obliteration of its vessels (extreme caution should be exercised in this treatment because excessive irradiation may cause a perforation of the cornea), for the obliteration of the vessels in trachomatous pannus to prevent the revascularization of the corneal stroma. Strontium is used before the transplantation of the cornea to prevent a vascular invasion, in a vascularized cataract, and in ulcer of the cornea.

For the purpose of increasing the focus dose in the metastatic region with the least possible damage to the surrounding tissue it was considered expedient to make use of radioactive colloid gold. The latter is used for the treatment of cancer of the uterus, the prostate and the rectum or for the prevention of relapses by being injected directly into the tumour, and for the prevention of metastases into the urinary bladder after the excision of the tumour. Radioactive colloid gold is used in the treatment of cancer of the genitalia and the vagina, in metastases into the vagina and in some parametric relapses following an operation for cancer of the uterus and ovaries.

The positive though relatively short-lived results of the injections of radioactive colloid gold into the regional metastases include the diminution and sometimes a complete cessation of pains, and an improvement in the general condition, while the injection of this isotope into the peritoneal cavity in malignant tumours terminates the accumulation of ascitic fluid, improves the general condition of the patients and prolongs their life.

Yttrium 90 has been used for treating metrorrhagias. This ß-radiator is introduced into the uterine cavity. The ß-radiations damage only the endometrium and do not affect the functions of the ovaries. The substance differs from the other ß-radiators by its high energy--2.2 Mev.

Radioactive sodium 24 is used in the treatment of papillomas of the urinary bladder; it is introduced in certain doses through a catheter into a balloon.

The foregoing enumeration of the uses of radioactive isotopes shows that atomic energy is playing an important role in medical practice and will increasingly contribute to the health of mankind.